PHYSICAL PROPERTIES
AND
TESTS OF LUBRICATING OILS

BY

B. ROBECHEK

N. A. STEINDLER

ARMOUR INSTITUTE OF TECHNOLOGY

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THE PHYSICAL PROPERTIES AND TESTS OF LUBRICATING OILS

A THESIS

PRESENTED BY

B. ROBECHEK AND N. A. STEINDLER

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APPROVED:

Geo. F. Gebhardt
Professor of Mechanical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

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PREFACE

There are many oils on the market today, which can be used for the lubrication of internal combustion motors. As it was impossible to obtain results from all of these oils, twenty-four of the most popular ones were chosen. Of all the oils experimented with, sample number nine was the most difficult to test. This oil is a thick, dark, heavy fluid upon which an emulsion and heat test could not be performed. Lubricating oils, for use in steam engines, were not considered in this thesis, for it is the question of automobile lubrication which is the most interesting to the authors. The names of the oils are withheld, that the confidence imparted to us, by the various manufacturers, might not be betrayed.

It has been our aim to make this thesis as concise and to the point as possible. We hope that the material embodied herein will be of interest and benefit to technical students.

27201

Finally, we wish to express our indebtedness to Professor James C. Peebles and Mrs. Julia Beveridge for the aid and many helpful suggestions it has been our good fortune to receive during the development of this thesis.

CONTENTS.

Page
Object 5
Elements of Oil Refining 6

Methods and Discussion of Oil Testing

Flash Point and Fire Point 17
Data 19
Heat Test 19
Data 21
Emulsion Test 21
Data 23
Gravity 23
Cold Test 26
Viscosity 26
Data 33

Curves (Following Data on Viscosity).

Bibliography 33

LIST OF ILLUSTRATIONS.

Page
Flash and Fire Point Apparatus 18
Heat Test Apparatus 20
Emulsion Test Apparatus 22
Gravity Test Apparatus 23
Viscosimeter 30

PHYSICAL PROPERTIES AND TESTS OF LUBRICATING OIL

Object.

In this thesis, we purpose discussing the method of refining, the physical properties, and the tests of lubricating oils. The tests described in this article have, to a considerable extent, been directly responsible for the present efficient lubrication of machinery. A continued study will surely result in more efficient lubrication, and in a great reduction in the amount of oil used per horse-power developed.

PHYSICAL PROPERTIES AND TESTS OF LUBRICATING OIL

Elements of Oil Refining.

Crude oils are not simple chemical compounds, but consist of an extremely complex mixture of compounds of the element carbon and the element hydrogen. Other elements such as sulphur, oxygen, nitrogen, and metallic salts, are present as impurities. Each one of these many compounds has its own definite physical properties.

Crude oils may be divided into two main families; those of paraffin and asphaltic base. There is no sharp line of separation between these groups, since most crude oils found in all fields may contain mixtures in variable percentage of hydrocarbon.

Crude oils of paraffin base have always been considered the best for the manufacture of lubricating oils.

There is a vast difference between petroleum as it flows from the earth and an efficient lubricating oil. It is necessary to sub-

ject the oil to many intricate and seldom divulged processes. A description of petroleum refining along broad lines is herewith given.

The crude oil is first deposited into storage tanks of large capacity, where a certain settling takes place. From the storage tanks, the crude oil is pumped into a large cylindrical boiler, called a "crude still". When this is filled up to a certain level, heat is applied, and vaporization and distillation commence.

Distillation, as applied to hydrocarbon oil, is the separation of the more volatile from the less volatile portions by vaporization, and later condensing them by passing the hot vapors through a cooled tube. Light hydrocarbons, like gasoline, vaporize very readily, whereas, heavy oils form practically no vapors at atmospheric pressure and temperature, therefore, it is necessary to heat and

boil crude petroleum in a closed vessel, in order to accomplish complete vaporization and separation of the different hydrocarbons. Since crude oil is a complex mixture of hydrocarbons, each of which has a different boiling point, a different temperature is required for the vaporization of each compound. Entrained gas and the lightest hydrocarbons pass over first, and as the temperature is increased, heavier and heavier hydrocarbons are vaporized.

The vapors formed are led through a pipe from the still and discharged into the base of an aerial tower condenser. From there, they pass up through alternate boxes and air-cooled tubes, where products of different boiling points are simultaneously condensed, and thus automatically separated into groups. The lightest products pass completely through the tower and flow in vapor form to a water-cooled condensing coil, where all light hydrocarbons,condensable

without the application of pressure, are liquefied and separated from the remaining vapors, which are further treated at a compressor plant, for the separation of very light hydro-carbons from the "fixed" gases. Of the remaining vapors, the heaviest condense upon striking the first air-cooled tubes, and the lightest upon striking the last tubes. Intermediate products, lying between the light and heavy ends, condense in the intermediate tubes, depending upon their respective boiling point. The vapors liquefying in different sections of the aerial condenser fall back into corresponding collector pans, whence each is led by way of a separate water-cooled coil to the storage tanks, called "running tanks". The liquids recovered in the collector pans are still at a temperature above their fire points, and it is necessary to cool them down to prevent spontaneous ignition, when they come into contact with air in the running

tanks.

Distillation continues until a residue of about fifteen percent remains, when the fires are drawn and the remaining oil is pumped from the still, through a cooler, into a running tank.

The quantity and quality of products obtained from the first separation depend upon the method of distillation employed, and from the base or "family" to which the crude petroleum belongs. This description, however, only concerns crude oil of paraffin base. High quality oils are obtained when the separation is made by distilling under vacuum, or by the use of fire in combination with steam injection. Due to the mixture of oil and water vapors in fire and steam distillation, oil vapors pass over at lower temperatures than were fire used alone. This prevents the occurrence of any serious "cracking" of the heavier products.

The prime object of subjecting the

group-distillates from the running tanks to different processes is to further separate each group into the final market form of the many products contained.

The secondary purpose of refining is to remove the impurities , color bearing, and unstable or unsaturated compounds and free carbon. It may be well to point out at this time that in the first group distillation there is no sharp line of demarcation between gasoline and illuminating oil ,or between any other similar fractions. Heavy constituents are mechanically carried over with the light portions,and more volatile products are mixed with the heavy parts. In order to completely separate these, further distillation is necessary.

The crude naphtha distillate is pumped from the running tank to an agitator where it is treated with sulphuric acid, washed with water to remove the free acid, and neutralized with

caustic soda, again washed and separated from the water. The treated naphtha is next sent to a steam still, where it is divided by distillation into various market grades of gasoline. From there, it is pumped to the finished naphtha storage tanks.

The illuminating oil distillate is pumped to a steam still, where the crude naphtha contained is separated by distillation and sent to the crude naphtha still. The illuminating oil remaining is sent to an agitator, where it is acid treated, washed, neutralized, rewashed, and filtered through Fuller's earth. It is then pumped to the finished kerosene lamp oil storage tanks.

The crude light lubricating distillate passes from the running tank to a steam and fire still, for the purpose of changing the character of the paraffin wax from the amorphous condition to wax that may be crystallized, and for separa-

ting the fuel oil content. The lubricating distillate then goes to a chilling tank where its temperature is lowered to such a degree as to cause crystallization of the wax. In this chilled condition, it is then pumped to a wax filter press, under high pressure, where it isseparated into crude scale wax and pressed lubricating distillate. The pressed distillate then goes to a steam and fire still, where the gas oil is separated from it. The remaining distillate is then divided into lubricating oils of different viscosity, varying from very light to medium light by fractional distillation.

The oils of different viscosities, resulting from this fractional distillation, are next sent to a Fuller's earth filter for the removal of color-bearing compounds and free carbon. From the filter, these oils are pumped to the finished lubricating oil storage tanks.

The crude scale wax is sent from the

wax filter press to a sweater, where it is separated into scale wax and oil. The scale wax then goes to a Fuller's earth filter, through which it passes to the finished paraffin wax tanks.

The crude heavy lubricating distillate follows the same course in processing as that indicated for the light distillate. Fuel oil and paraffin wax are separated in the same manner. The fractional distillation of the remaining oil results in lubricating oils of heavier body than those recovered by the processing of the light lubricating distillate.

Crude cylinder stock, being very viscous and difficult to handle, is greatly thinned down by mixing it with naphtha. It is then sent to a chilling tank, where the amorphous paraffin wax settles out. This separation of paraffin wax from all grades of oil has the effect of lowering the cold test. The oil-naphtha

portion is separated and pumped to a Fuller's earth filter for the removal of color-bearing compounds and free carbon. From the filter, it passes on to a steam still, where it is separated into naphtha and low cold test cylinder stock. From the still, the oil is sent to a tank, where it is blown with air to remove traces of moisture. After this air-drying process, the cylinder stock is pumped to the finished storage tanks.

Oils manufactured from the lubricating distillates of paraffin base, crude petroleum, are usually not heavy enough for heavy and extra heavy grades. It is, therefore, necessary to blend these filtered, "straight run", lubricating oils with highly filtered, low cold test cylinder stock of extremely heavy body, to produce oils of heavy and extra heavy body, required in some types of internal combustion engines.

PHYSICAL PROPERTIES AND TESTS OF LUBRICATING OIL

The refining of asphalt base petroleum is substantially the same as presented in the methods of refining paraffin base crude oil. The residue is, however, asphalt, and, except in the case of paraffin-asphalt or semi-asphalt base petroleum, no wax distillate is obtained.

In the distillation of asphalt base petroleum to a tar, sometimes called asphaltum oil or fluxing oil, the distillates are cut according to gravity.

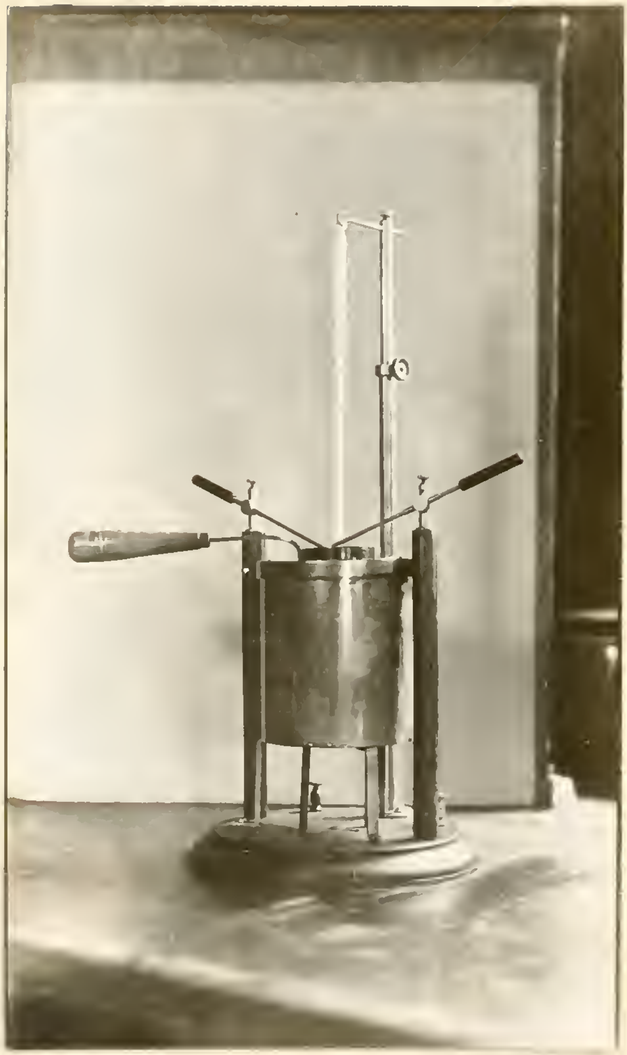
PHYSICAL PROPERTIES AND TESTS OF LUBRICATING OIL

The Methods and Discussion of Oil Testing.

Among the features very often discussed both by buyers and sellers of lubricating oils, and but slightly understood by either of them, is the matter of physical tests. These are:- flash, fire, heat, emulsion, gravity, cold, and viscosity. After many years of experience in practice, these tests offer a reliable basis for determining the suitability of oil for use in internal combustion motors.

Flash Point and Fire Point:-

All lubricating oils, when sufficiently heated, give off vapor. The "flash point" is the temperature at which the amount of vapor given off is sufficient to form an inflammable or mildly explosive mixture with the air over the surface of the oil, so that on the application of a spark, the gaseous mixture ignites and burns with a momentary flash. As the temperature of the oil rises, more vapor is given



Flash and Fire Point Apparatus

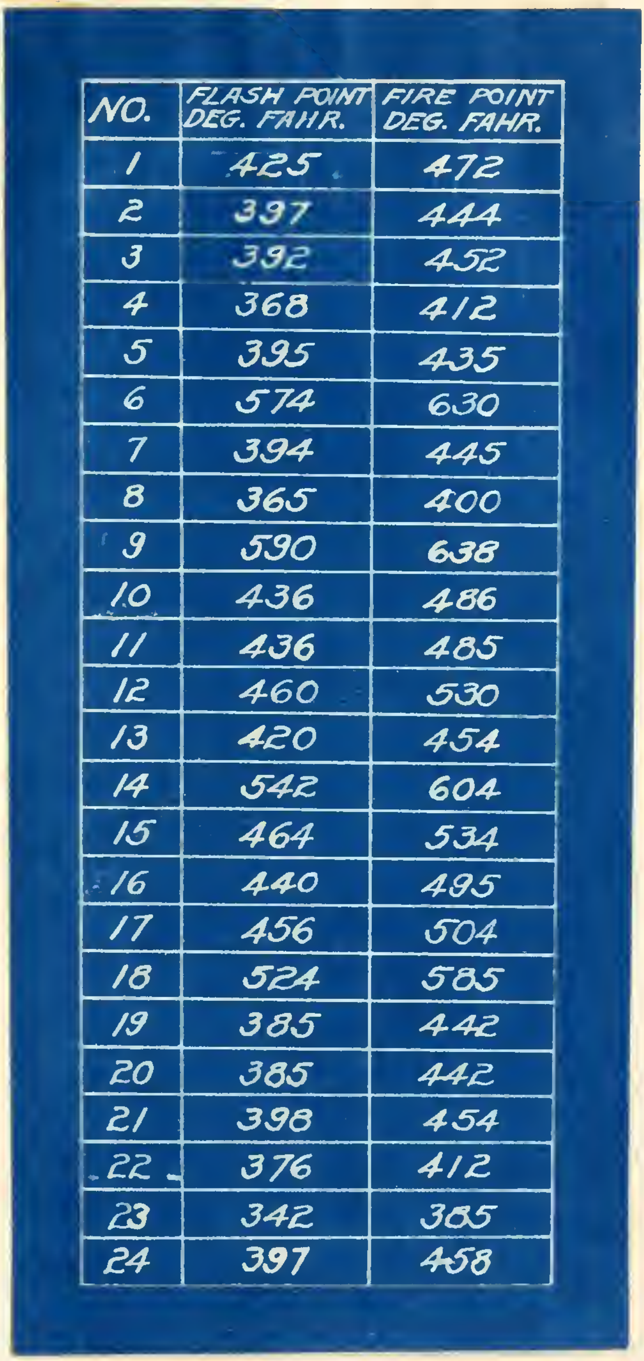
off, and when the production of vapor is rapid enough to maintain a continuous flame, the oil takes fire and burns. The temperature at which this occurs is called the "firing point" or "burning point" of the oil.

The methods used for determining the flashing and firing points are as follows:

The oil for the flash test is heated electrically. The test is made by means of a spark from the spark coil, the terminals being about one-fourth of an inch apart and one-fourth of an inch above the surface of the oil. The reading of the thermometer is noted when a blue flash is seen across the surface.

The burning or firing point is determined by continuing the heating until the oil catches fire and burns when the spark is applied.

The determination of these points, more especially of the flash point, is of great



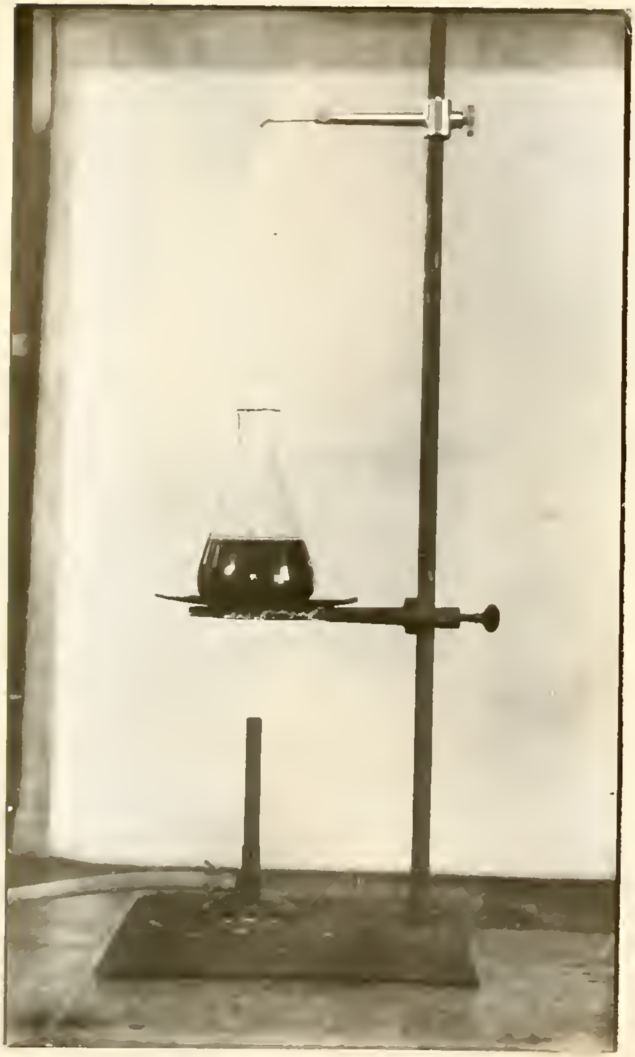
NO.	FLASH POINT DEG. FAHR.	FIRE POINT DEG. FAHR.
1	425	472
2	397	444
3	392	452
4	368	412
5	395	435
6	574	630
7	394	445
8	365	400
9	590	638
10	436	486
11	436	485
12	460	530
13	420	454
14	542	604
15	464	534
16	440	495
17	456	504
18	524	585
19	385	442
20	385	442
21	398	454
22	376	412
23	342	385
24	397	458

importance in the examination of lubricating oils.

Oils of low flashing point are unsafe to use because,at ordinary temperatures of operation, a heavy sediment of sulphuric acid compound, very gummy in nature, is left on the bearings when the volatile matter is driven off. This deposit destroys the bearings and prevents smoothness of operation. It is, therefore, of great importance to detect the presence of "sulpho" compounds at the flash point.

Heat Test:-

According to the Molecular Theory of Heat, matter consists of units or parts called molecules, which are composed of smaller units of the elements, called atoms. The addition of heat energy to a body either increases the kinetic energy of its molecules or increases their potential energy. The important changes in substances, produced by heat, are changes in

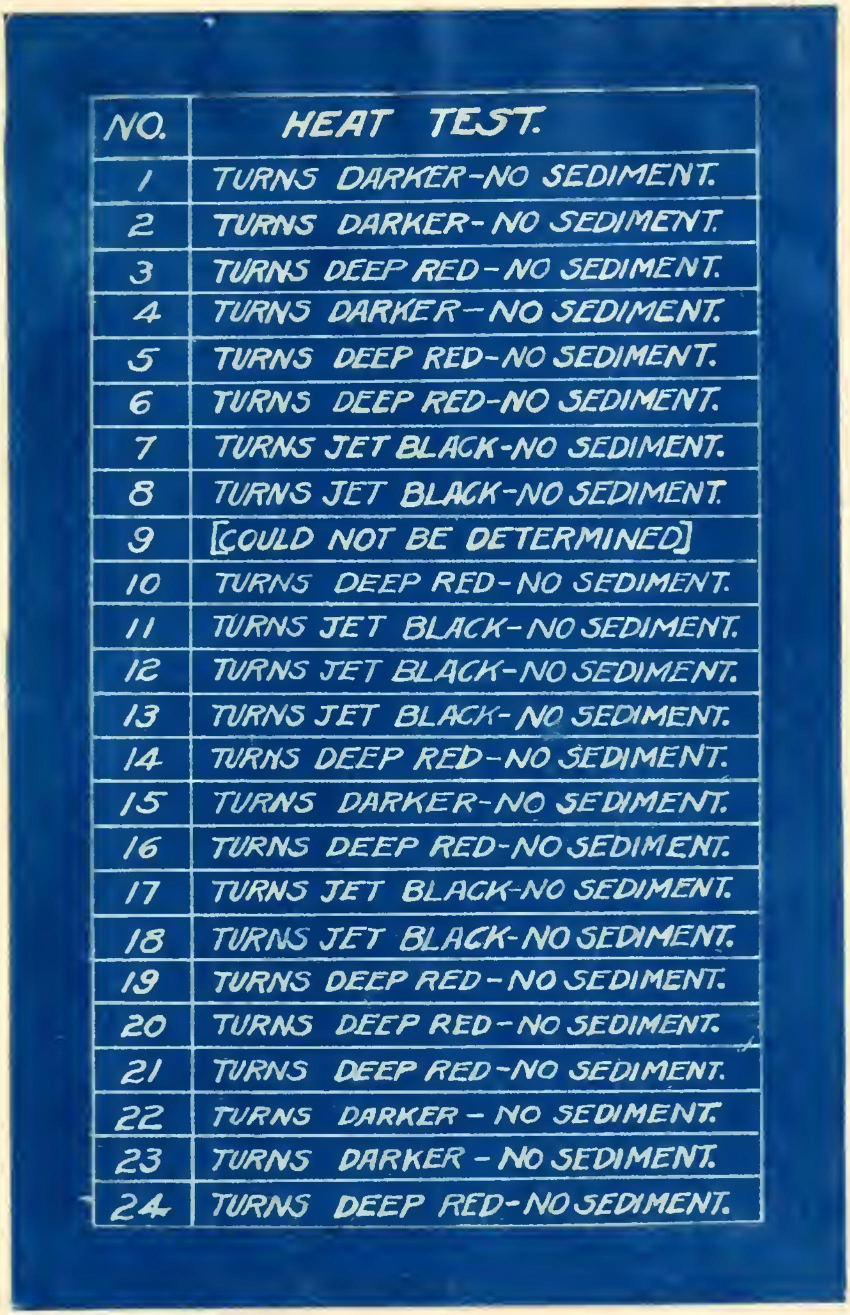


Heat Test Apparatus

arrangement of molecules with respect to one another, and changes in state.

When an oil is heated, the molecules are disarranged and evaporation takes place. If the oil is poor, the lighter molecules will rise, leaving a deposit of black, carbon-like sediment in the bottom of the vessel. This proves the presence of sulphuric or sulphonic acid compounds, showing that the oil was not properly neutralized in the refining process. If the oil is good, it will darken in color but remain perfectly clear and without sediment, even after standing twenty-four hours. This test is unfailing and so important, that it is recommended to oil purchasers as a feature to be incorporated in their specifications.

In order to perform a heat test, fill an Ehrlemeyer flask about half full with the oil to be tested. Heat it up slowly over an

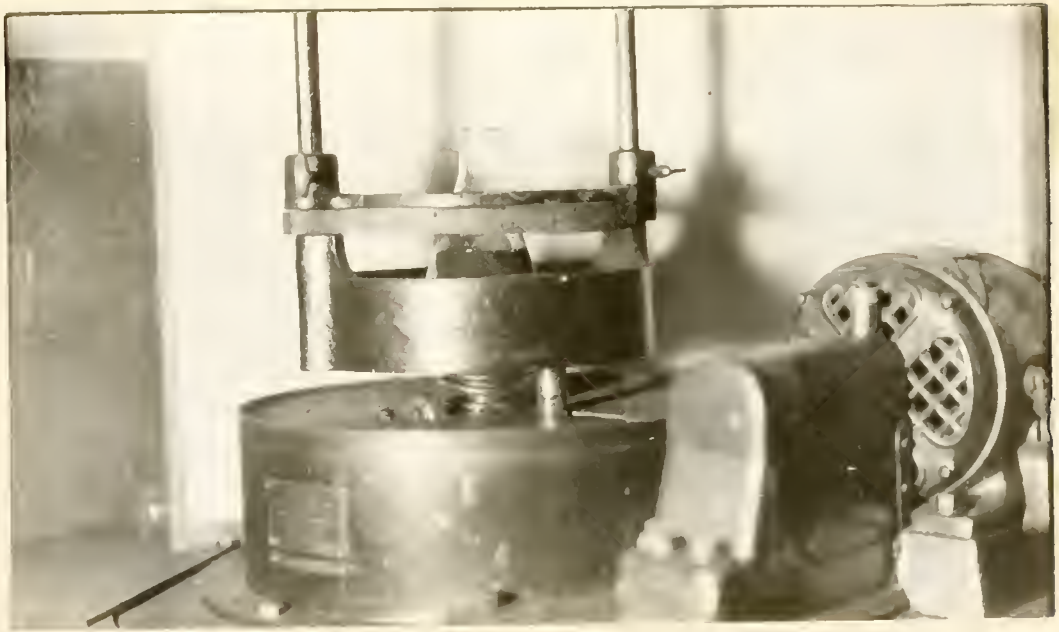


NO.	HEAT TEST.
1	TURNS DARKER-NO SEDIMENT.
2	TURNS DARKER- NO SEDIMENT.
3	TURNS DEEP RED - NO SEDIMENT.
4	TURNS DARKER-- NO SEDIMENT.
5	TURNS DEEP RED- NO SEDIMENT.
6	TURNS DEEP RED-NO SEDIMENT.
7	TURNS JET BLACK-NO SEDIMENT.
8	TURNS JET BLACK-NO SEDIMENT.
9	[COULD NOT BE DETERMINED]
10	TURNS DEEP RED- NO SEDIMENT.
11	TURNS JET BLACK- NO SEDIMENT.
12	TURNS JET BLACK-NO SEDIMENT.
13	TURNS JET BLACK- NO SEDIMENT.
14	TURNS DEEP RED-NO SEDIMENT.
15	TURNS DARKER-NO SEDIMENT.
16	TURNS DEEP RED-NO SEDIMENT.
17	TURNS JET BLACK-NO SEDIMENT.
18	TURNS JET BLACK-NO SEDIMENT.
19	TURNS DEEP RED - NO SEDIMENT.
20	TURNS DEEP RED - NO SEDIMENT.
21	TURNS DEEP RED -NO SEDIMENT.
22	TURNS DARKER - NO SEDIMENT.
23	TURNS DARKER - NO SEDIMENT.
24	TURNS DEEP RED-NO SEDIMENT.

open flame until yellow vapors appear above the surface of the oil. This temperature is about the temperature of the flash point. Hold the oil at this temperature for fifteen minutes. A comparison of the heated with an unheated sample of the same oil gives the determination of its quality.

Emulsion Test:-

When an oil mixes permanently with water, it loses its lubricating qualities. A good oil shows a fine, white line of demarcation between the oil and the clear water after being mixed, indicating the absence of acid compounds. A poor oil will mix permanently with the water, appearing as a curdled mass, floating upon milky water below. This indicates the presence of sulphuric or sulphonic acid compounds. The curdled portion is a sort of sulphuric acid soap, and the amount of curd shows the quantity of "sulpho" compounds present.



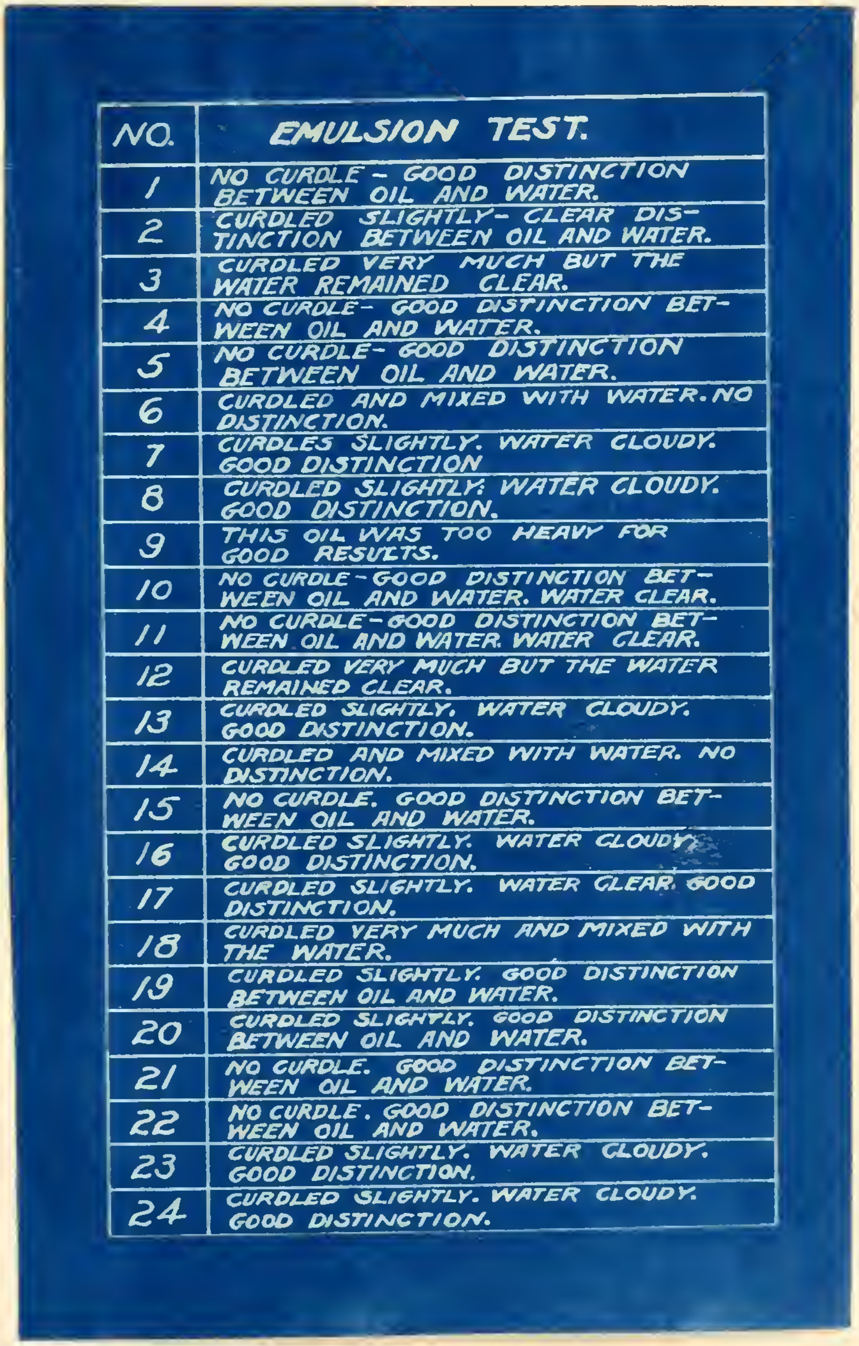
Emulsion Test Apparatus

PHYSICAL PROPERTIES AND TESTS OF LUBRICATING OIL

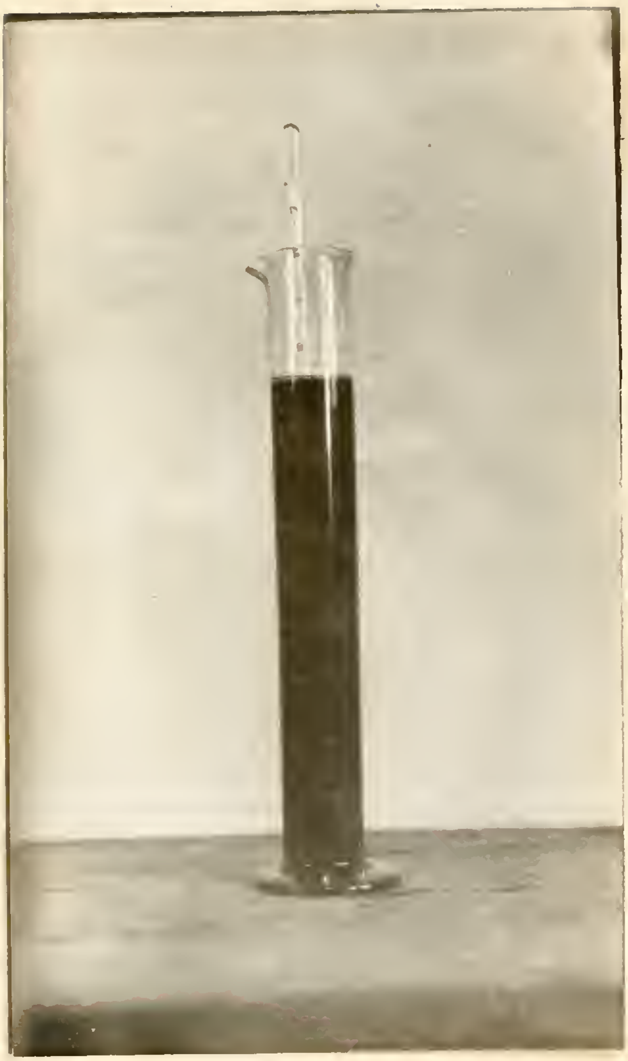
The object of the emulsion test is exactly the same as that of the heat test. To persons making a study of oils, it is worthy of notice because of the fact that there is a certain quantity of water present in the crank case of motors, due to the condensation there of the products of combustion.

To determine the quality of the oil, fill a bottle one-third full with the oil to be tested. Pour in an equal amount of water, leaving a space of one-third free about the oil and water. Cork and shake the bottle, vigorously, for thirty minutes in a shaking machine. Then set it aside for twenty-four hours. The quality can be determined by seeing whether the oil curdles, or not.

Word of Caution: Ultra violet rays in sunlight cause oils, otherwise good, to readily emulsify. Sample submitted to this test should, therefore, not be taken from bottles kept in shop windows,



NO.	EMULSION TEST.
1	NO CURDLE - GOOD DISTINCTION BETWEEN OIL AND WATER.
2	CURDLED SLIGHTLY - CLEAR DISTINCTION BETWEEN OIL AND WATER.
3	CURDLED VERY MUCH BUT THE WATER REMAINED CLEAR.
4	NO CURDLE - GOOD DISTINCTION BETWEEN OIL AND WATER.
5	NO CURDLE - GOOD DISTINCTION BETWEEN OIL AND WATER.
6	CURDLED AND MIXED WITH WATER. NO DISTINCTION.
7	CURDLES SLIGHTLY. WATER CLOUDY. GOOD DISTINCTION
8	CURDLED SLIGHTLY. WATER CLOUDY. GOOD DISTINCTION.
9	THIS OIL WAS TOO HEAVY FOR GOOD RESULTS.
10	NO CURDLE - GOOD DISTINCTION BETWEEN OIL AND WATER. WATER CLEAR.
11	NO CURDLE - GOOD DISTINCTION BETWEEN OIL AND WATER. WATER CLEAR.
12	CURDLED VERY MUCH BUT THE WATER REMAINED CLEAR.
13	CURDLED SLIGHTLY. WATER CLOUDY. GOOD DISTINCTION.
14	CURDLED AND MIXED WITH WATER. NO DISTINCTION.
15	NO CURDLE. GOOD DISTINCTION BETWEEN OIL AND WATER.
16	CURDLED SLIGHTLY. WATER CLOUDY. GOOD DISTINCTION.
17	CURDLED SLIGHTLY. WATER CLEAR. GOOD DISTINCTION.
18	CURDLED VERY MUCH AND MIXED WITH THE WATER.
19	CURDLED SLIGHTLY. GOOD DISTINCTION BETWEEN OIL AND WATER.
20	CURDLED SLIGHTLY. GOOD DISTINCTION BETWEEN OIL AND WATER.
21	NO CURDLE. GOOD DISTINCTION BETWEEN OIL AND WATER.
22	NO CURDLE. GOOD DISTINCTION BETWEEN OIL AND WATER.
23	CURDLED SLIGHTLY. WATER CLOUDY. GOOD DISTINCTION.
24	CURDLED SLIGHTLY. WATER CLOUDY. GOOD DISTINCTION.



Gravity Test Apparatus

or elsewhere after long exposure to the direct rays of the sun.

Gravity:-

Specific gravity is the ratio of the weight of a solid or liquid substance to that of an equal volume of water. Of all the methods for ascertaining the specific gravity, the hydrometer method is the most rapid, and providing the instrument used is correctly graduated, or its error exactly known, very accurate results may be obtained.

Hydrometers may be divided into two classes, those giving specific gravity directly, and those graduated with arbitrary scales, namely, the Beaume', which is in general use throughout the United States. This instrument, when allowed to float freely in an oil or other liquid, sinks to a depth corresponding to the density of the liquid. The Beaume' gravity value is then read at the point where the surface of the liquid

intersects the scale. The liquid should be maintained at a constant temperature of 60° Fahrenheit, if not, correction should be made for temperature.

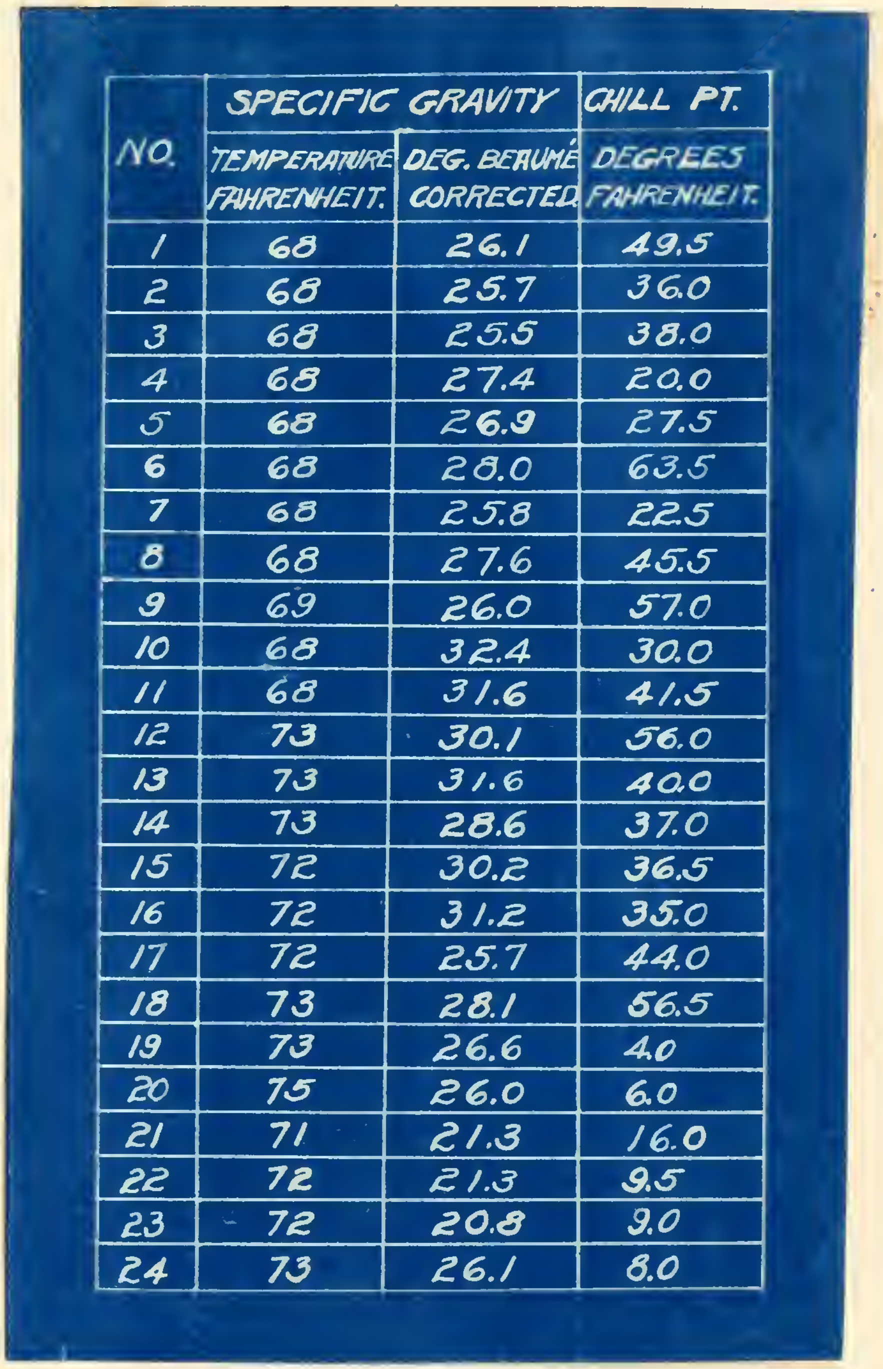
Cold Test:-

The chill or cold test of an oil is the lowest temperature at which the oil will pour. This characteristic need only be taken into consideration because of its effect upon the free circulation of oil through exterior feed pipes, where pressure is not applied. The cold test, is, however, in no way indicative of the lubricating or heat-resisting qualities of an oil.

The behavior of lubricating oils, when nearing the freezing point, is altogether different than the simple fluids such as water, glycerine, etc. The latter have a fixed and accurate freezing point, at which a complete change from the liquid to the solid state takes place, but lubricating oils, which are mixtures of bodies of

various melting points, behave like solutions and frequently deposit some portion of their constituents before the whole mixture solidifies. The "setting" point of an oil will, therefore, vary according to whether it be regarded as a temperature at which solid matter commences to separate, or the temperature at which the oil completely loses its fluidity.

Mineral oils assume their permanent state, for any given temperature, much more rapidly than the fixed oils, and should, therefore, not be stirred, as the net-work of solid hydrocarbons, which sometimes causes such oils to set before they have wholly solidified, is broken up by the stirring, and the "setting" point is thereby lowered. Mineral lubricating oils frequently undergo a change in their solidifying points by previous heating, and it is, therefore, important that the portion used for the "setting" point determination should not



NO.	SPECIFIC GRAVITY		CHILL PT.
	TEMPERATURE FAHRENHEIT.	DEG. BEAUMÉ CORRECTED.	DEGREES FAHRENHEIT.
1	68	26.1	49.5
2	68	25.7	36.0
3	68	25.5	38.0
4	68	27.4	20.0
5	68	26.9	27.5
6	68	28.0	63.5
7	68	25.8	22.5
8	68	27.6	45.5
9	69	26.0	57.0
10	68	32.4	30.0
11	68	31.6	41.5
12	73	30.1	56.0
13	73	31.6	40.0
14	73	28.6	37.0
15	72	30.2	36.5
16	72	31.2	35.0
17	72	25.7	44.0
18	73	28.1	56.5
19	73	26.6	4.0
20	75	26.0	6.0
21	71	21.3	16.0
22	72	21.3	9.5
23	72	20.8	9.0
24	73	26.1	8.0

have been recently used for any other test which has involved heating above the atmospheric temperature.

There are a number of methods that may be pursued to determine the chill point; the most common of these, and the one used in our determinations is as follows: Put about an inch of the oil to be tested in a test tube. Insert a thermometer and place the tube in a mixture of chipped ice and salt. Allow the sample to cool sufficiently so that a small lump will adhere to the thermometer when it is removed from the tube. Hold the thermometer at an angle of about 45°, and note the temperature at which the oil drops from the bulb. This temperature is the setting or chill point.

Viscosity:-

The viscosity of an oil is an indication of what may be expressed as the fluidity of the body, or the cohesiveness of the molecular con-

stituents of the oil.

All liquids exhibit viscosity, although in varying degree. Thus, if a vessel of water be tilted and then quickly brought back to its original position, so as to set the water in oscillatory motion, it will be found that with each swing, the amplitude of the oscillation diminishes, and that in a very short time, the movement dies away or becomes imperceptible, and the liquid comes to rest in an exactly horizontal position.

If a similar experiment be made with sperm oil, a much greater resistance to movement will be observed. The oscillations produced will not only be much slower, but will also be fewer in number. With very heavy oils, no oscillations whatever are produced; but a steady flow is brought about until the face of the liquid becomes horizontal again. In all cases, the movement ceases sooner or later, and it is

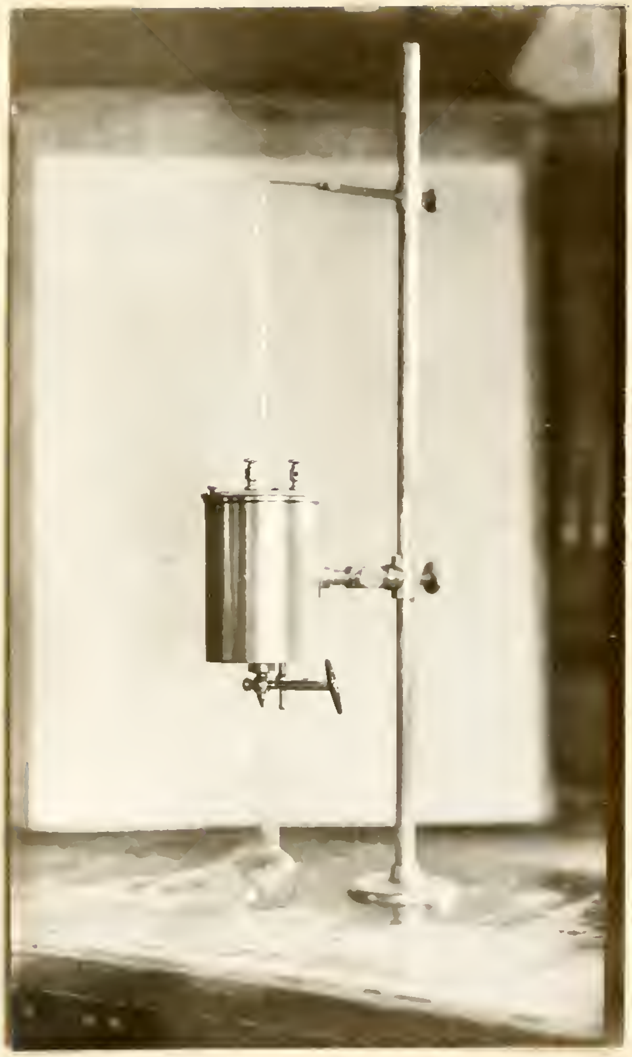
the internal friction or viscosity of the liquid which stops the motion.

Before mineral oils were introduced as lubricants, engineers had little reason to study the theory of viscosity, or to specify the particular fluidy of the oils they wished to make use of, for the number of animal and vegetable oils available for lubrication is limited, and the degree of viscosity they exhibit does not vary much in different samples. A little experience is usually sufficient to determine the most suitable description of oil for the purpose in view. Since the introduction of mineral lubricating oils, which can be prepared of any desired viscosity, the measurement of this property and the study of its influence upon lubrication have assumed great practical importance.

At low speeds, especially under heavy loads, and in all cases where a complete oil film cannot form between the friction surfaces,

the viscosity and oiliness of the lubricant are of great importance. These properties, though distinct, are related in some way, for it will generally be found, with oils of the same class, that the friction reducing power at low speeds is in the same order as the viscosity. Everything depends, however, upon the speed and load, for from the moment the surfaces commence to move relatively to each other, the oil tends to be forced between them. Therefore, as the speed increases and the film becomes thicker and more complete, so the reduction of friction becomes more and more dependent upon the viscosity and less upon the oiliness or the body of the lubricant.

Determinations of viscosity, made by measuring the resistance offered to the motion of discs or cylinders immersed in liquids, are, for the most part, unsatisfactory. In such cases, turbulent motion is locally, if not



Viscosimeter

generally, set up, and the results are misleading. For this reason, such methods of measuring, or attempting to measure the viscosity, was not pursued. The best way to measure viscosity, and the one which is universally used, is to note the time it takes for a quantity of the oil to flow from a nozzle of given diameter, under a set pressure and temperature.

With rise of temperature, the viscosity of liquids decreases, sometimes very rapidly, until a certain temperature is reached, where excess heat will not lower the viscosity. The curves on the tests of viscosities of the various oils bear out this statement.

There are many discussions concerning viscosity as an index to lubrication. Thurston states that a liquid, to act as a lubricant, must possess enough "body" or combined capillarity and viscosity to keep the surfaces between which it is interposed from coming into contact

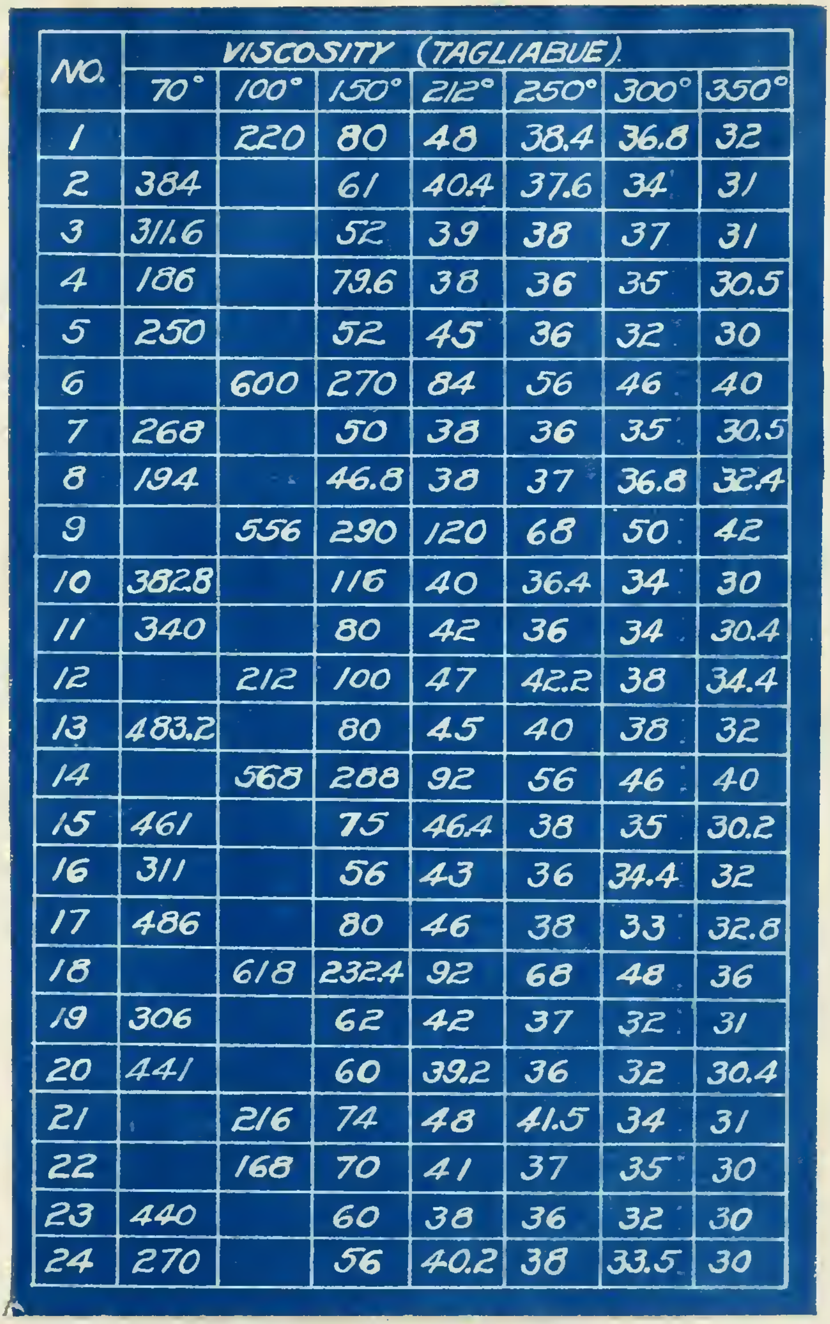
with one another. On the other hand, J. Veitch Wilson states that viscosity is not the only property by which the anti-frictional value of an oil is determined. The differentiating principle must be attributed to some other property. Cecil P. Poole states the following: "Viscosity, or any other characteristic considered alone, is practically worthless as a criterion; the viscosity of cylinder oils at ordinary temperatures is a rough and unsatisfactory guide. With the percentage of animal or vegetable fat limited to a low quantity however, and the viscosity taken at a high temperature, this characteristic is a most valuable criterion when considered in combination with others."

Although viscosity may not be regarded, by some engineers, an index to the lubricating properties of an oil, it is the most important property which can be measured in the laboratory

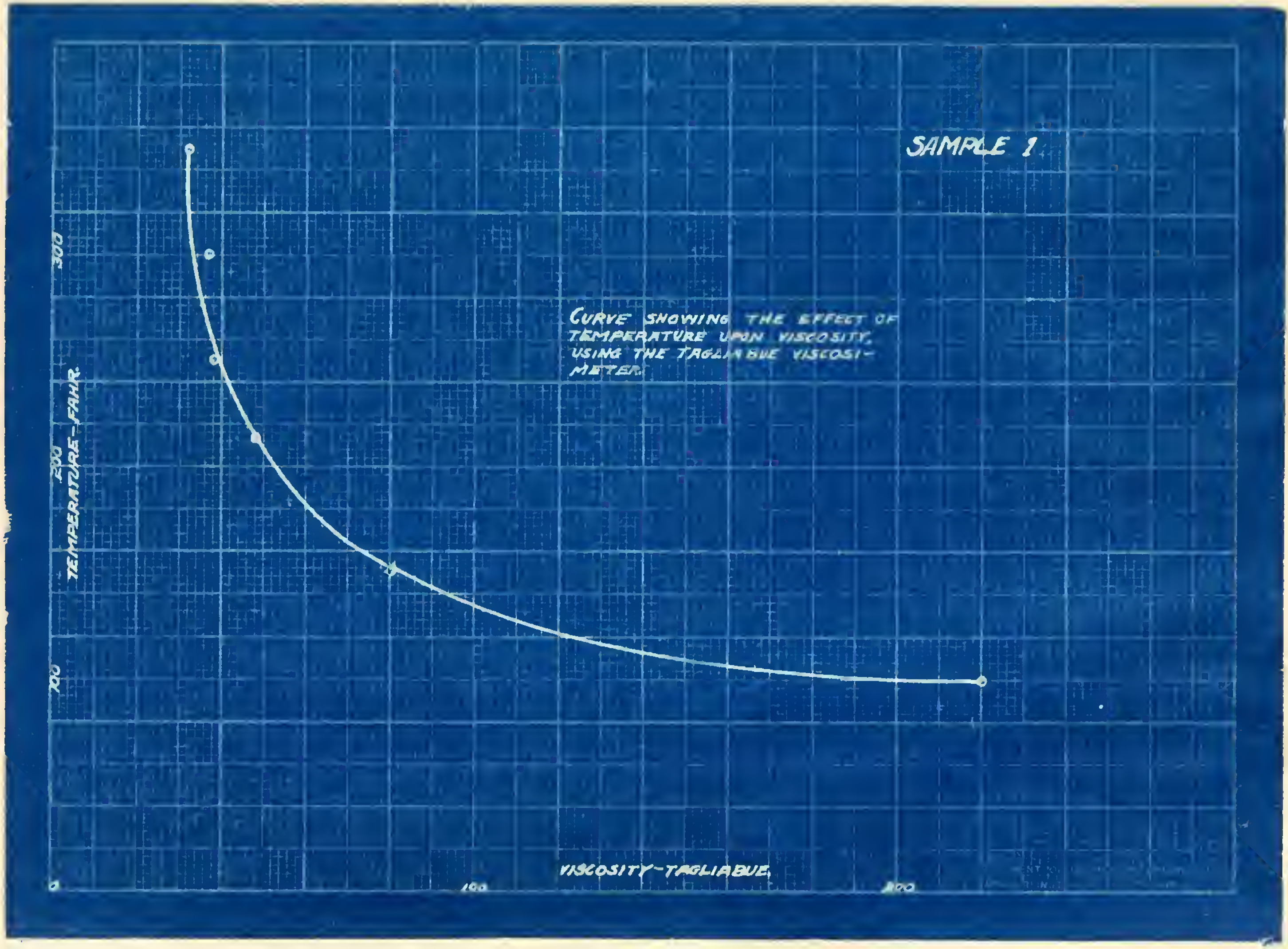
today. By this test, one can tell where an oil is to be used, whether it can be used for heavy lubrication, or light lubrication. Probably through lack of knowledge and information regarding this essential, it is seldom favored with even a thought by the immediate buyer or seller.

It should be appreciated by the practical man, that the tests of lubricating oils give only approximate results. Thus, any one viscosimeter, as ordinarily made, will give consistent results on the same material at the same temperature. However, different instruments of the same type, and apparently exactly alike, will give results on the same material which vary several percent.

No rigid directions can be given for the choice of oils for given purposes. It is best to try various lubricants until one is found which gives satisfactory results.

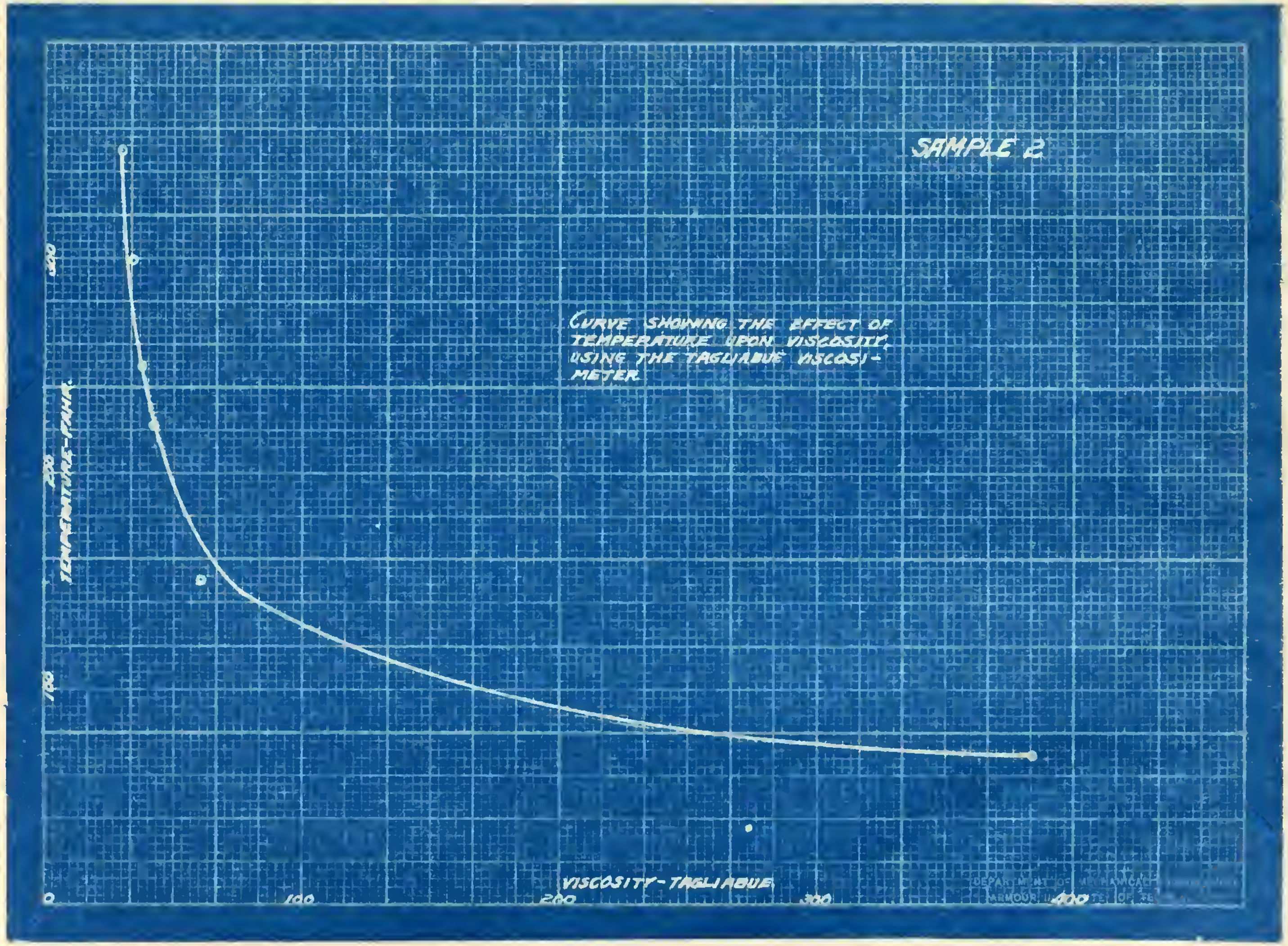


NO.	VISCOSITY (TAGLIABUE).						
	70°	100°	150°	212°	250°	300°	350°
1		220	80	48	38.4	36.8	32
2	384		61	40.4	37.6	34	31
3	311.6		52	39	38	37	31
4	186		79.6	38	36	35	30.5
5	250		52	45	36	32	30
6		600	270	84	56	46	40
7	268		50	38	36	35	30.5
8	194		46.8	38	37	36.8	32.4
9		556	290	120	68	50	42
10	382.8		116	40	36.4	34	30
11	340		80	42	36	34	30.4
12		212	100	47	42.2	38	34.4
13	483.2		80	45	40	38	32
14		568	288	92	56	46	40
15	461		75	46.4	38	35	30.2
16	311		56	43	36	34.4	32
17	486		80	46	38	33	32.8
18		618	232.4	92	68	48	36
19	306		62	42	37	32	31
20	441		60	39.2	36	32	30.4
21		216	74	48	41.5	34	31
22		168	70	41	37	35	30
23	440		60	38	36	32	30
24	270		56	40.2	38	33.5	30



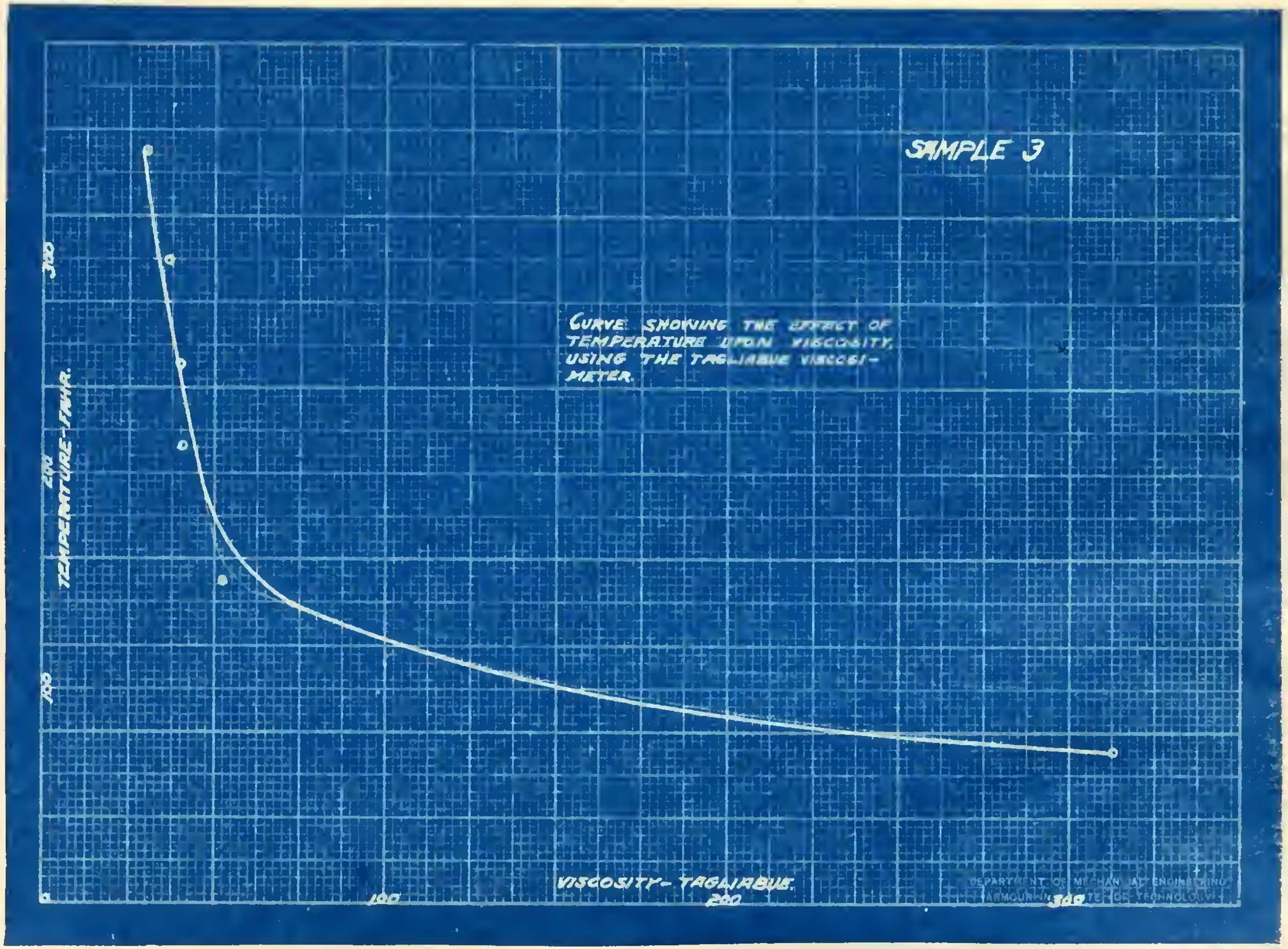
SAMPLE 1

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.



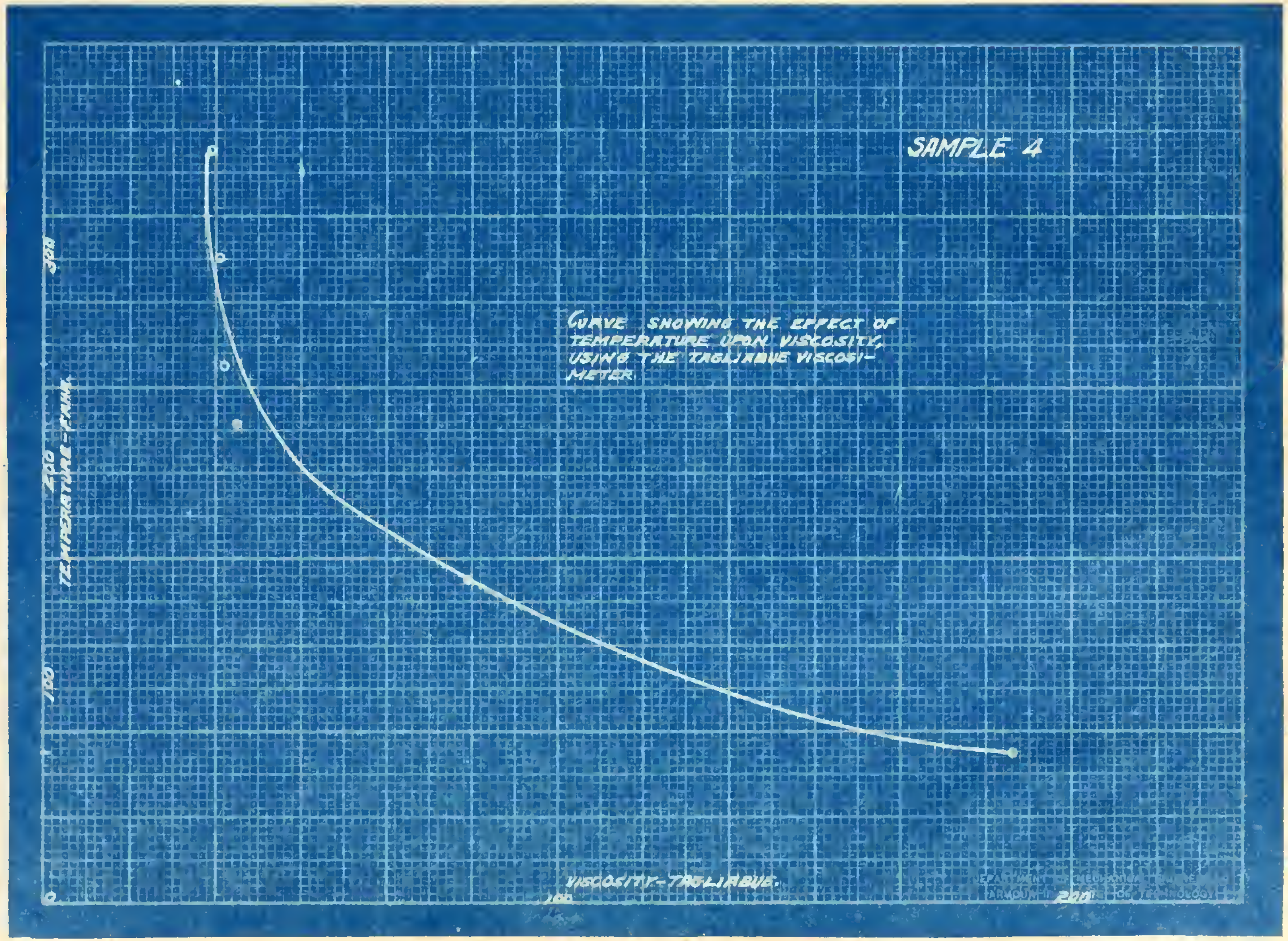
SAMPLE 2

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.



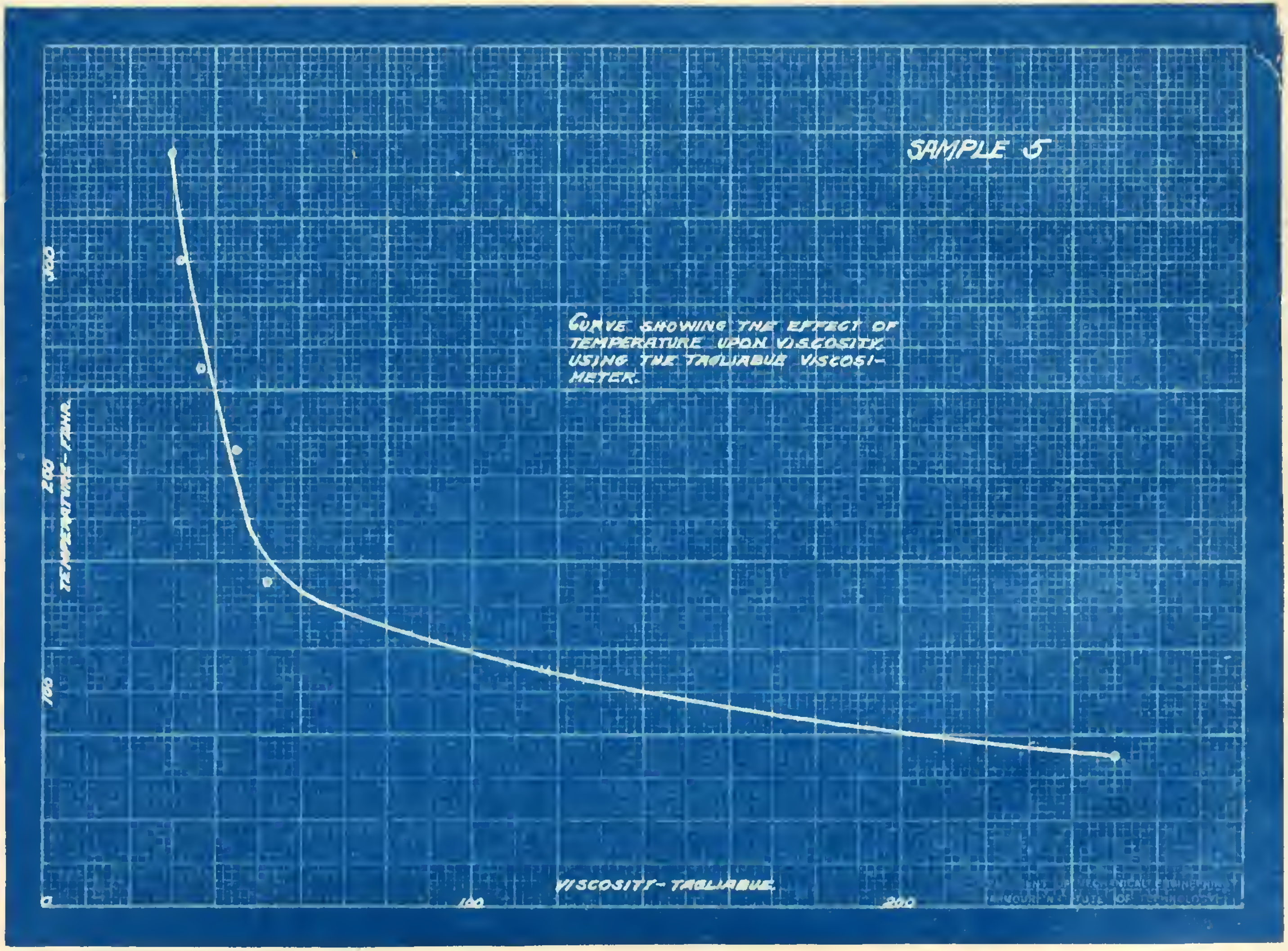
SAMPLE 3

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.



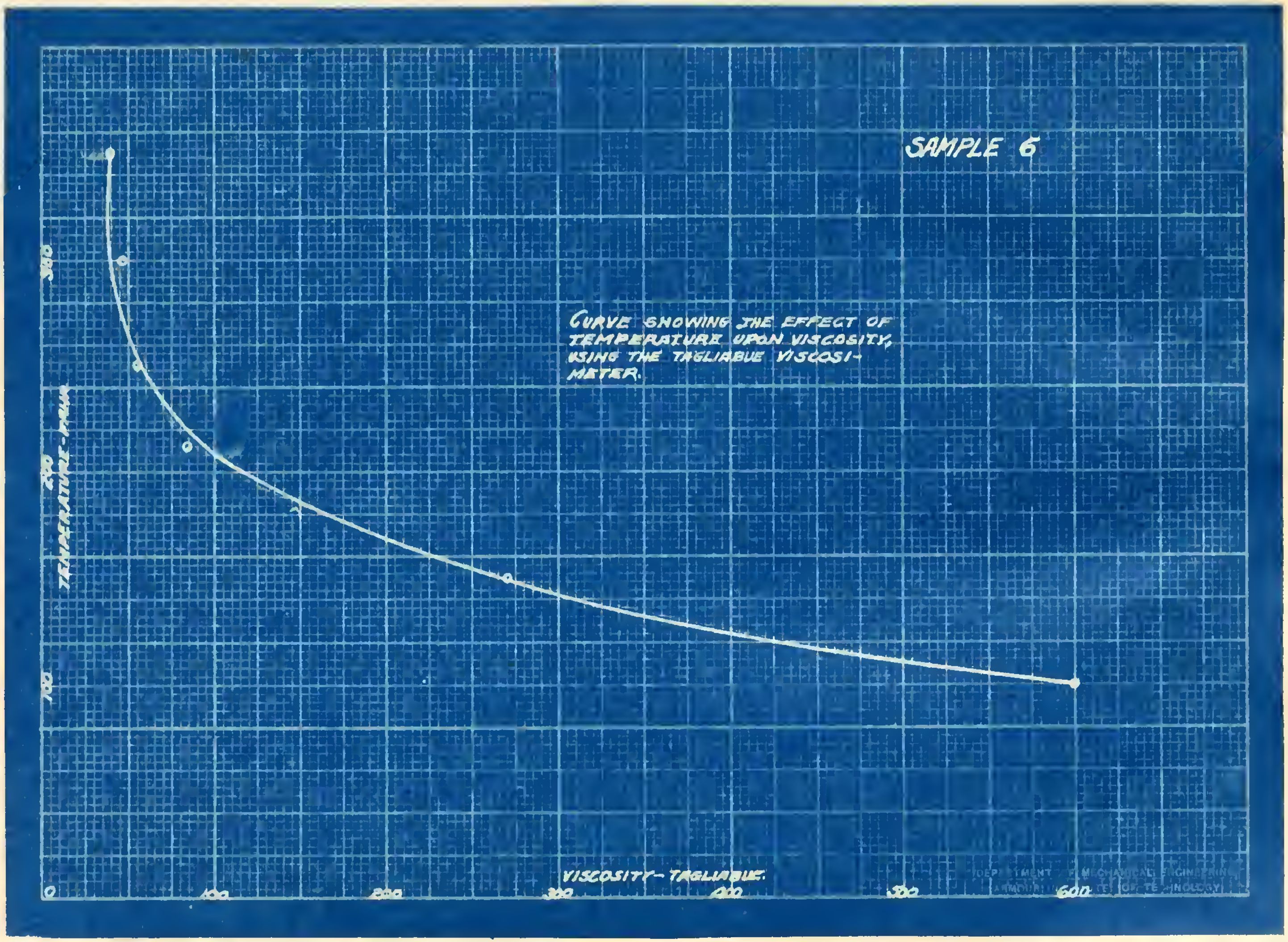
SAMPLE 4

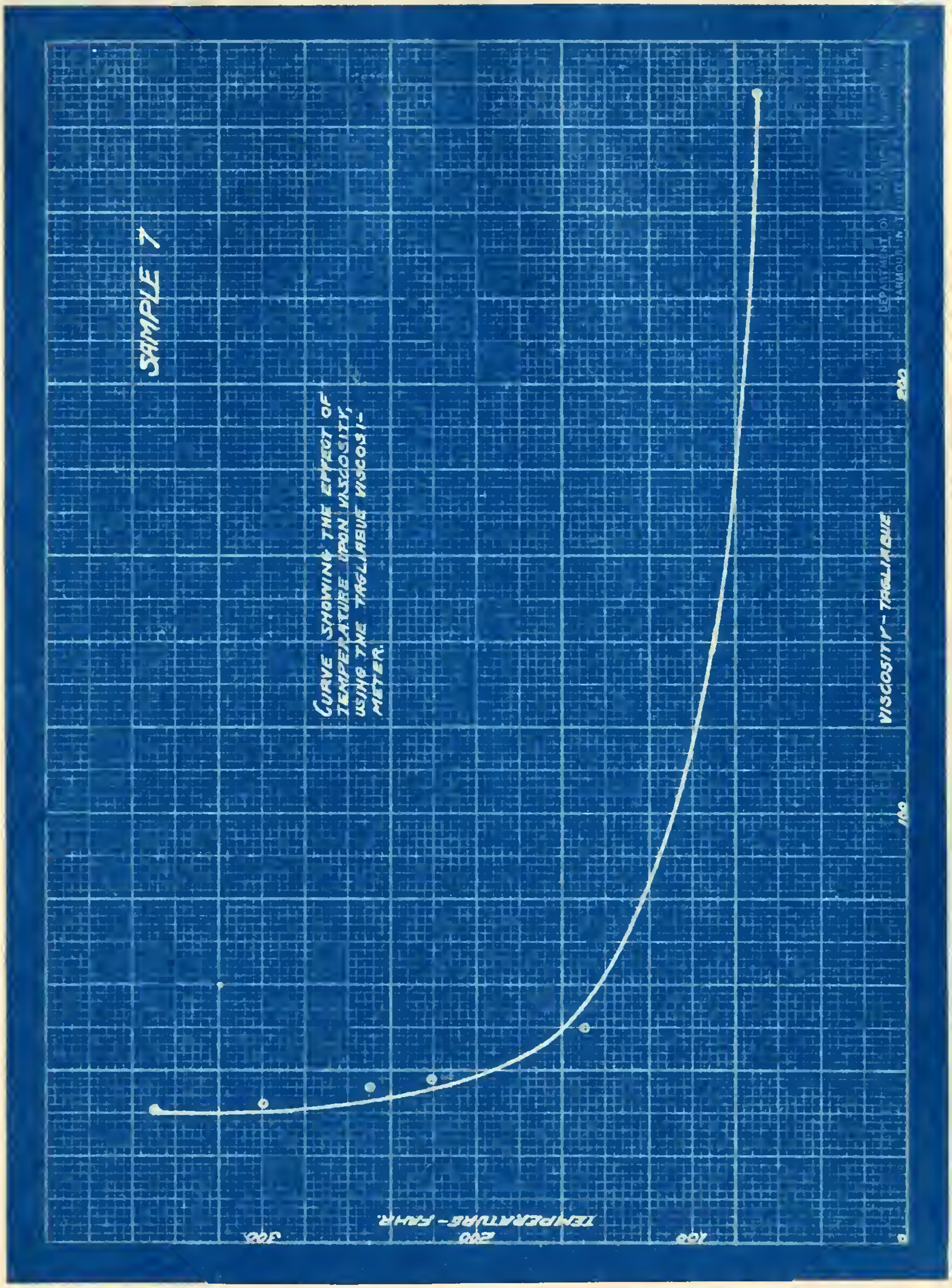
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.

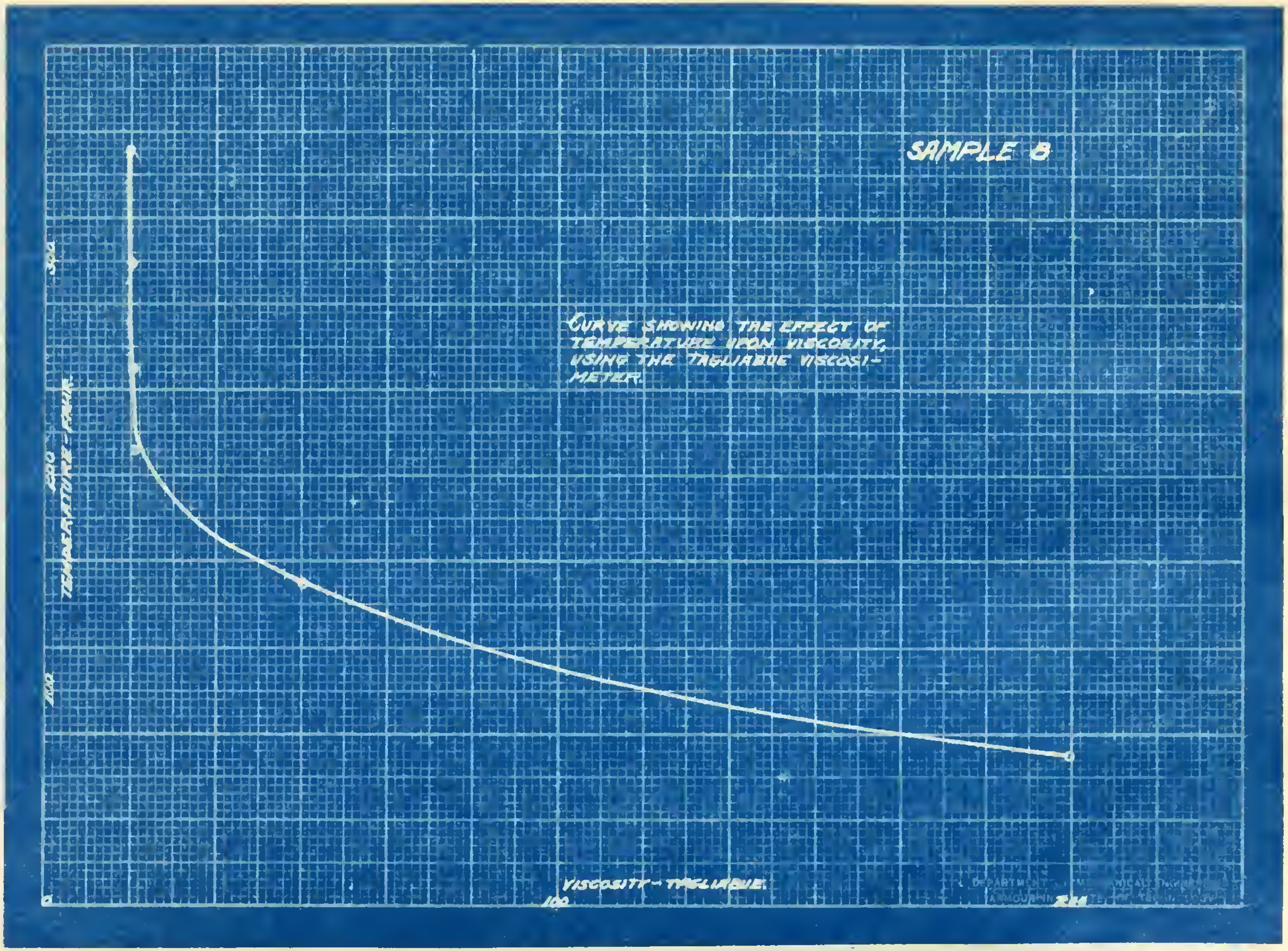


SAMPLE 5

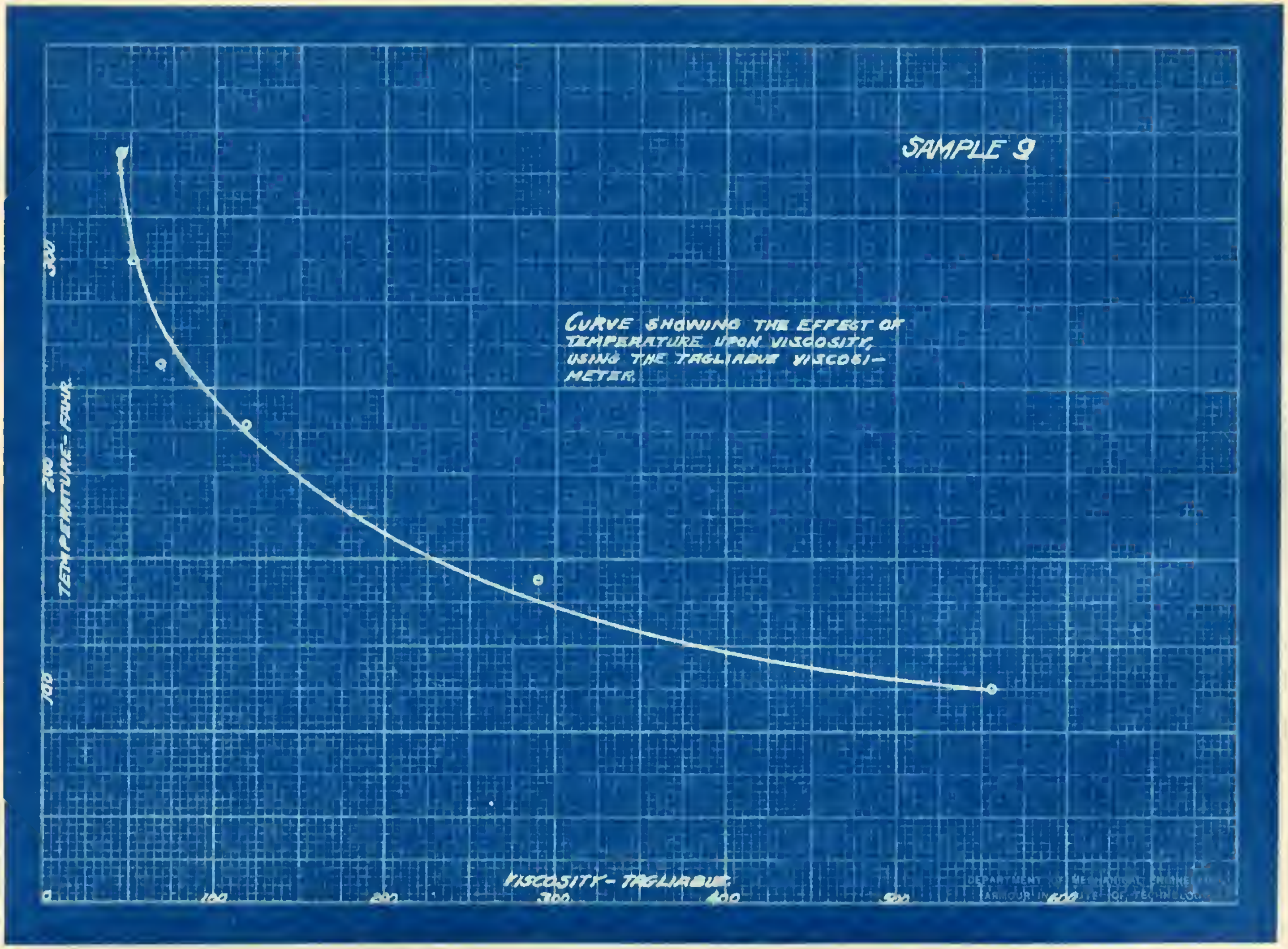
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY. USING THE TAGLIABUE VISCOSIMETER.

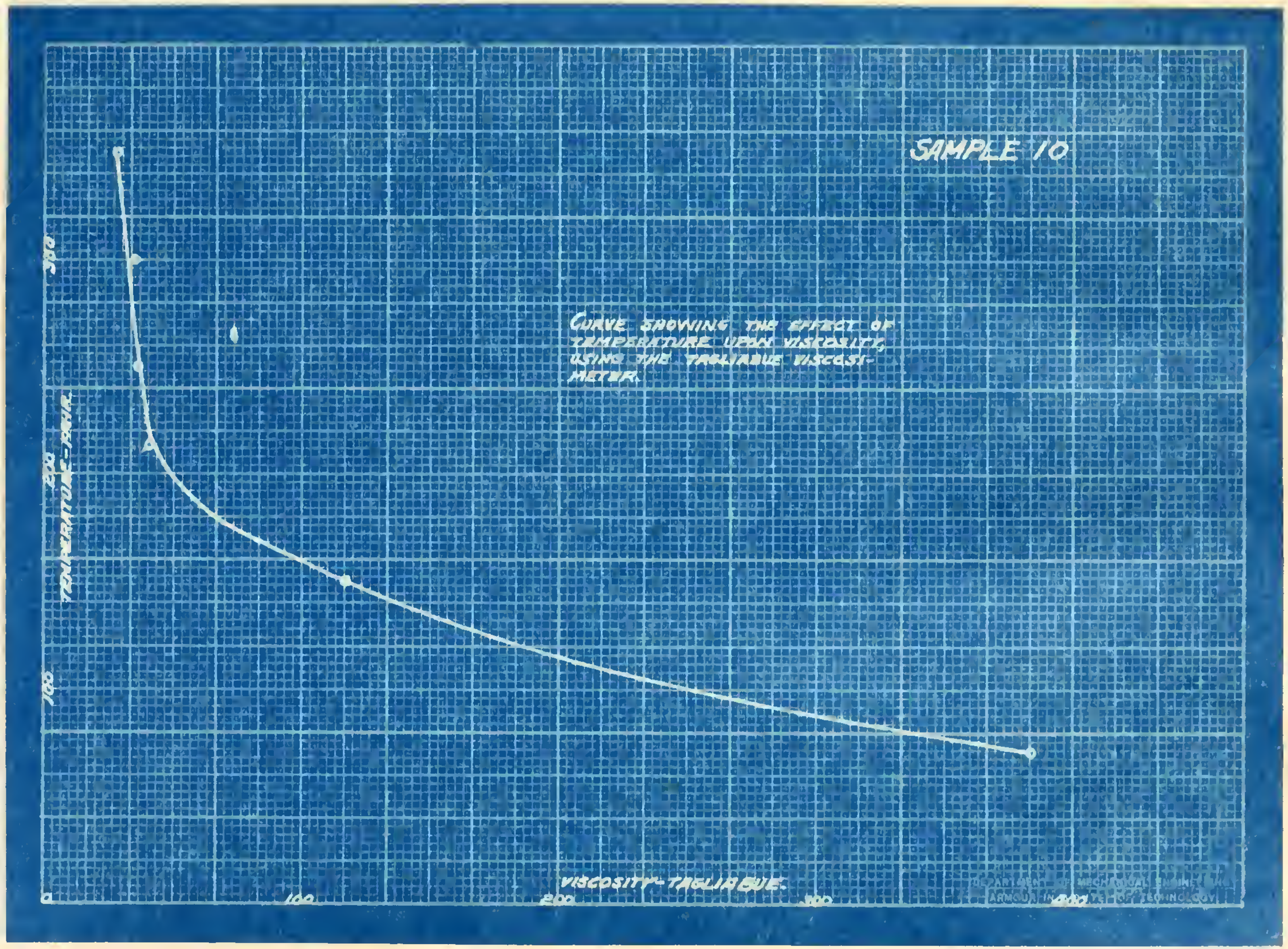


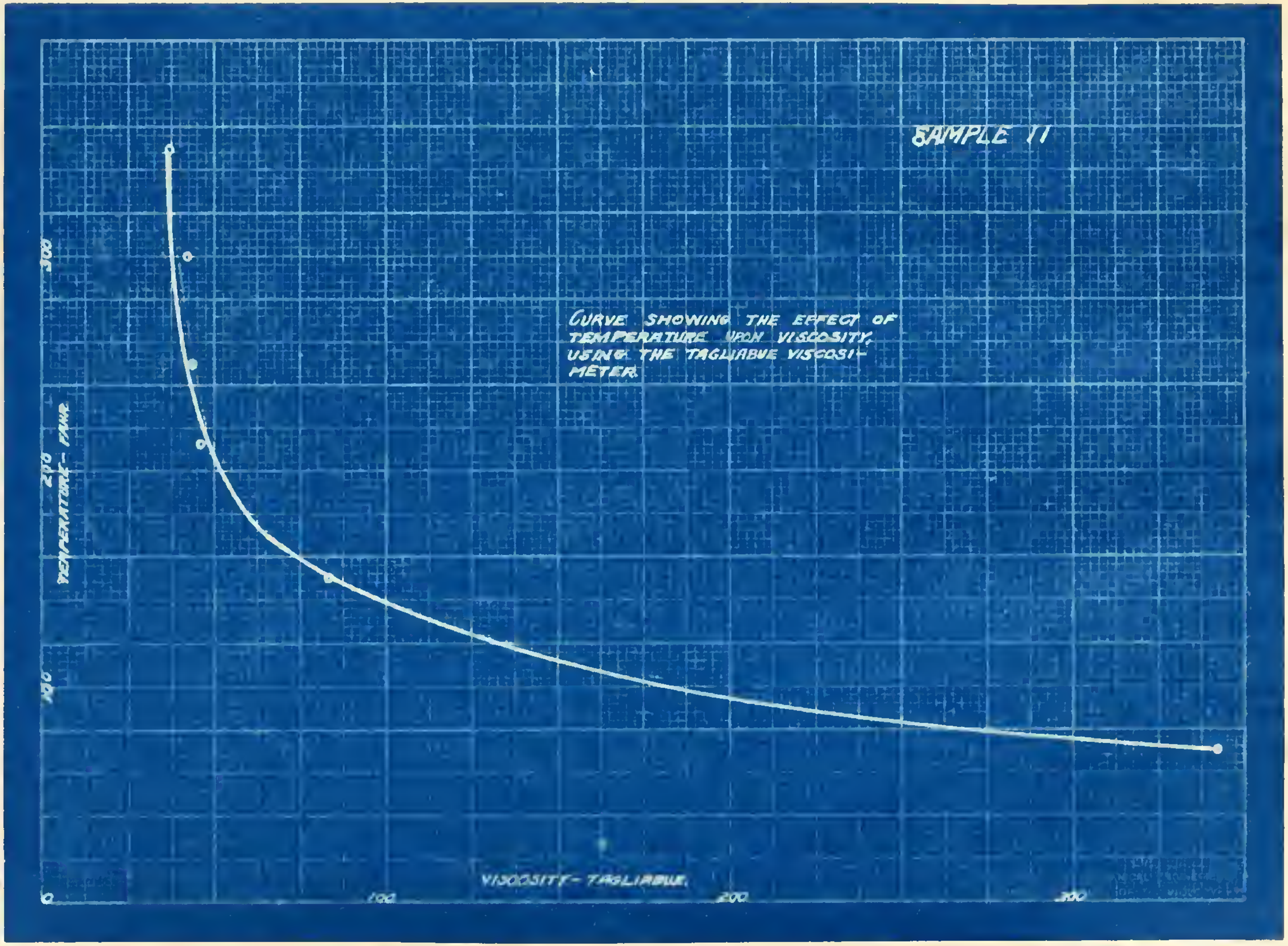
SAMPLE 7
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.
VISCOSITY - TAGLIABUE
0
100
200
TEMPERATURE - FAHR.
100
200
300
DEPARTMENT OF
ARMOUR INST


SAMPLE B

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.

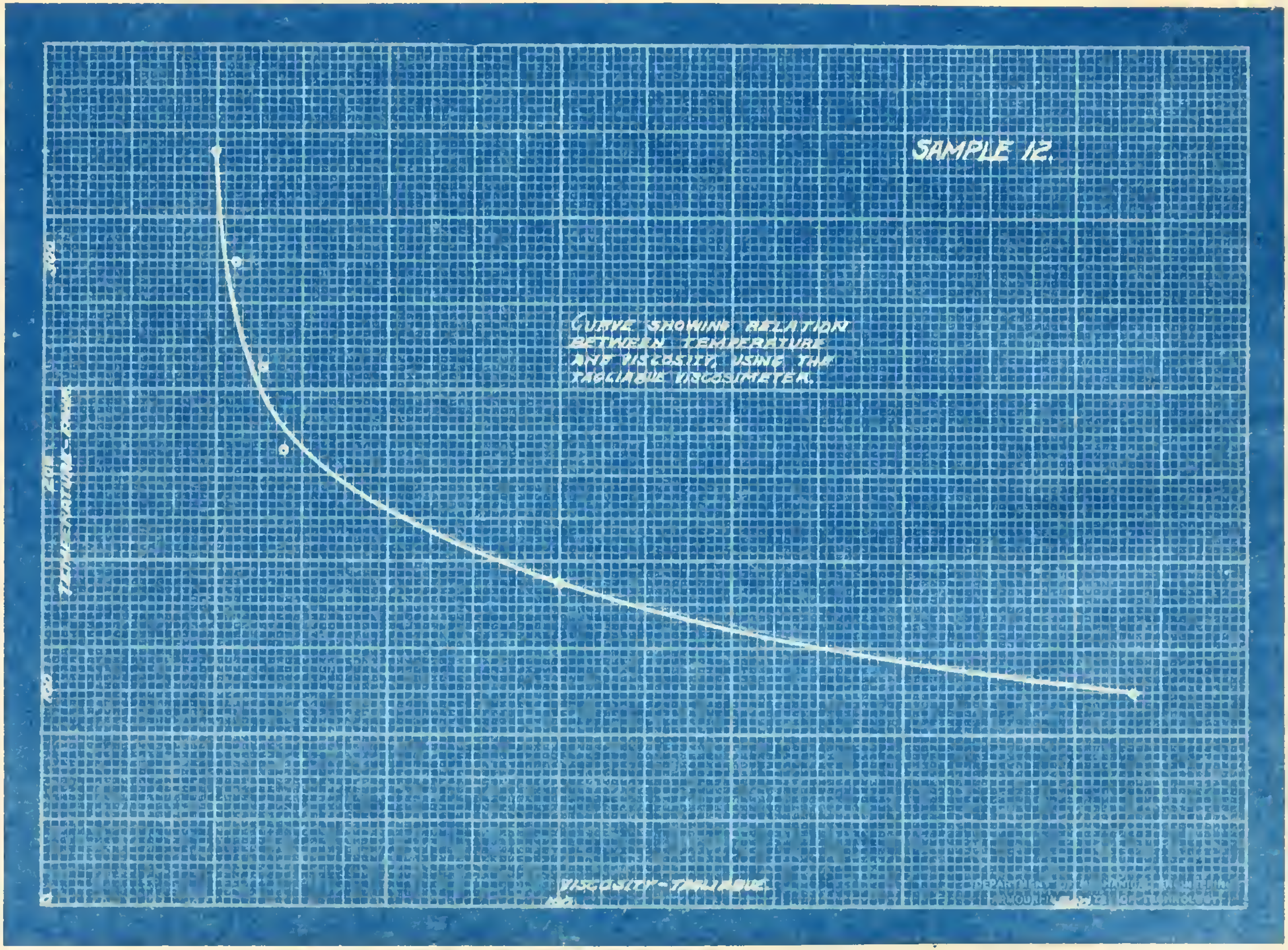

SAMPLE 9
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.
TEMPERATURE - FAHR.
100
200
300
VISCOSITY - TAGLIABUE
0
100
200
300
400
500
600
DEPARTMENT OF MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY


SAMPLE 10
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.
TEMPERATURE-FAHR.
300
200
100
VISCOSITY-TAGLIABUE.
0
100
200
300
400
DEPARTMENT OF MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY



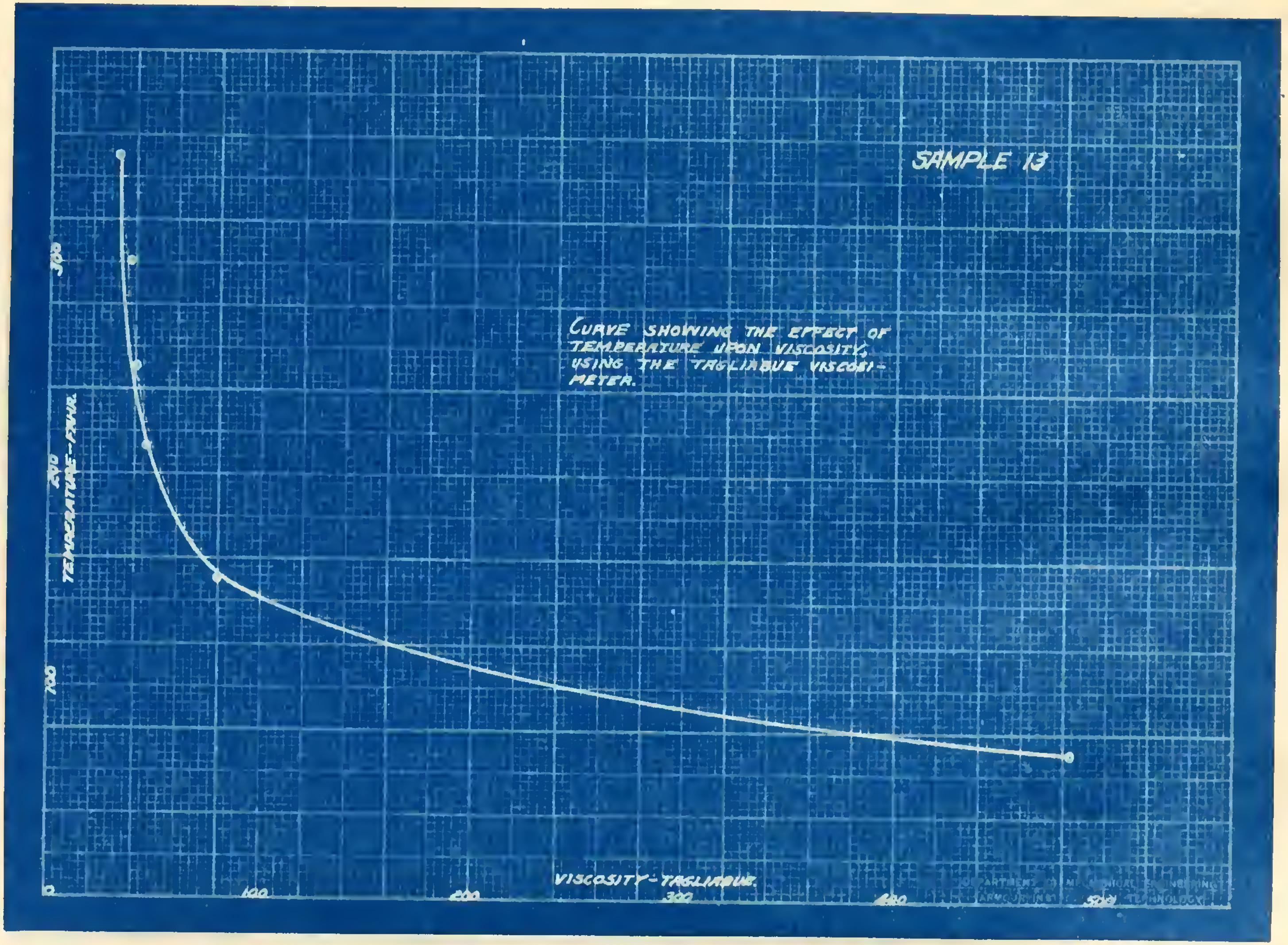
SAMPLE 11

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.

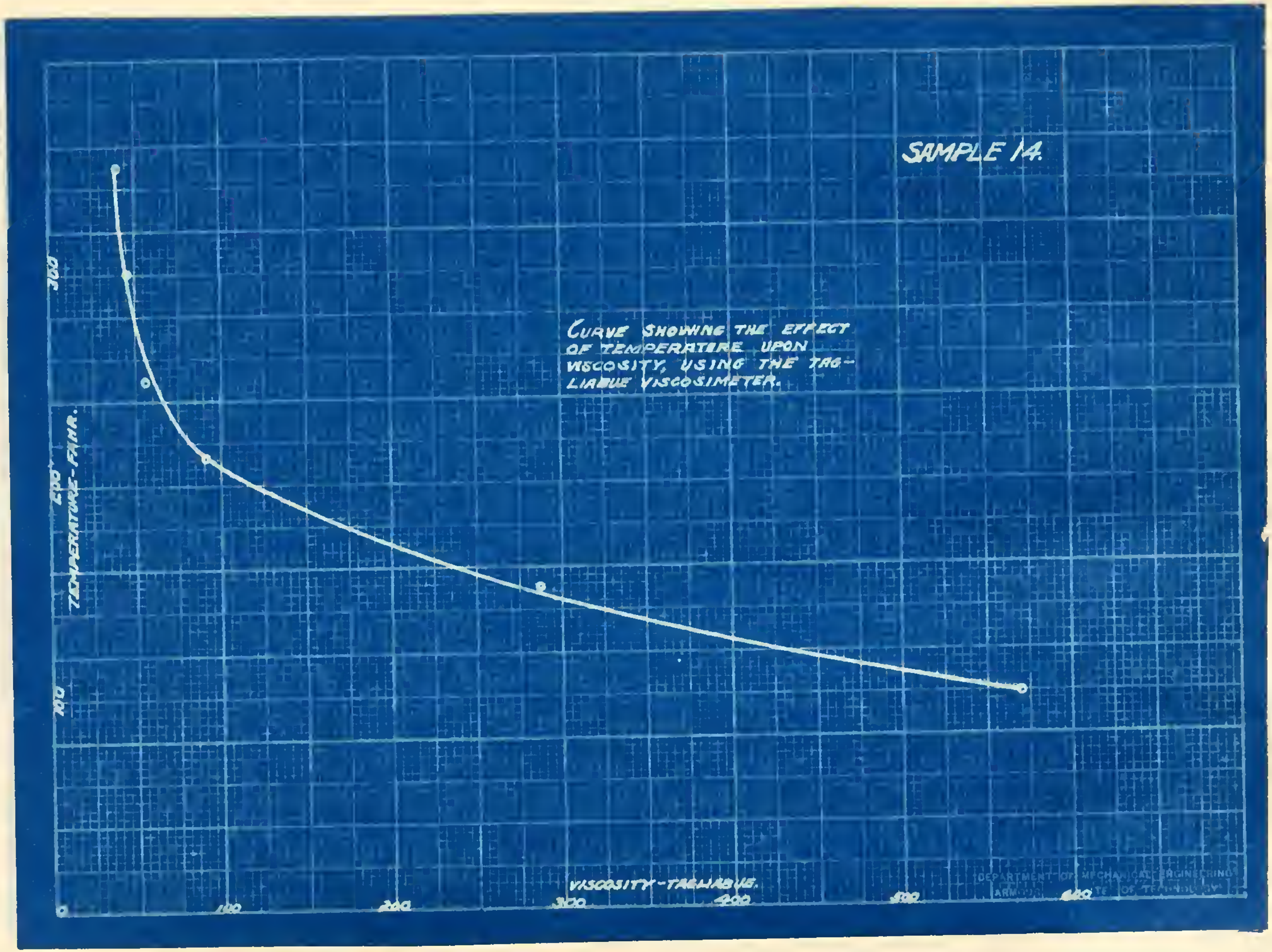


SAMPLE 12.

CURVE SHOWING RELATION BETWEEN TEMPERATURE AND VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.



CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.


SAMPLE 14.
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.
TEMPERATURE-FAHR.
300
200
100
VISCOSITY-TAGLIABUE.
0
100
200
300
400
500
600
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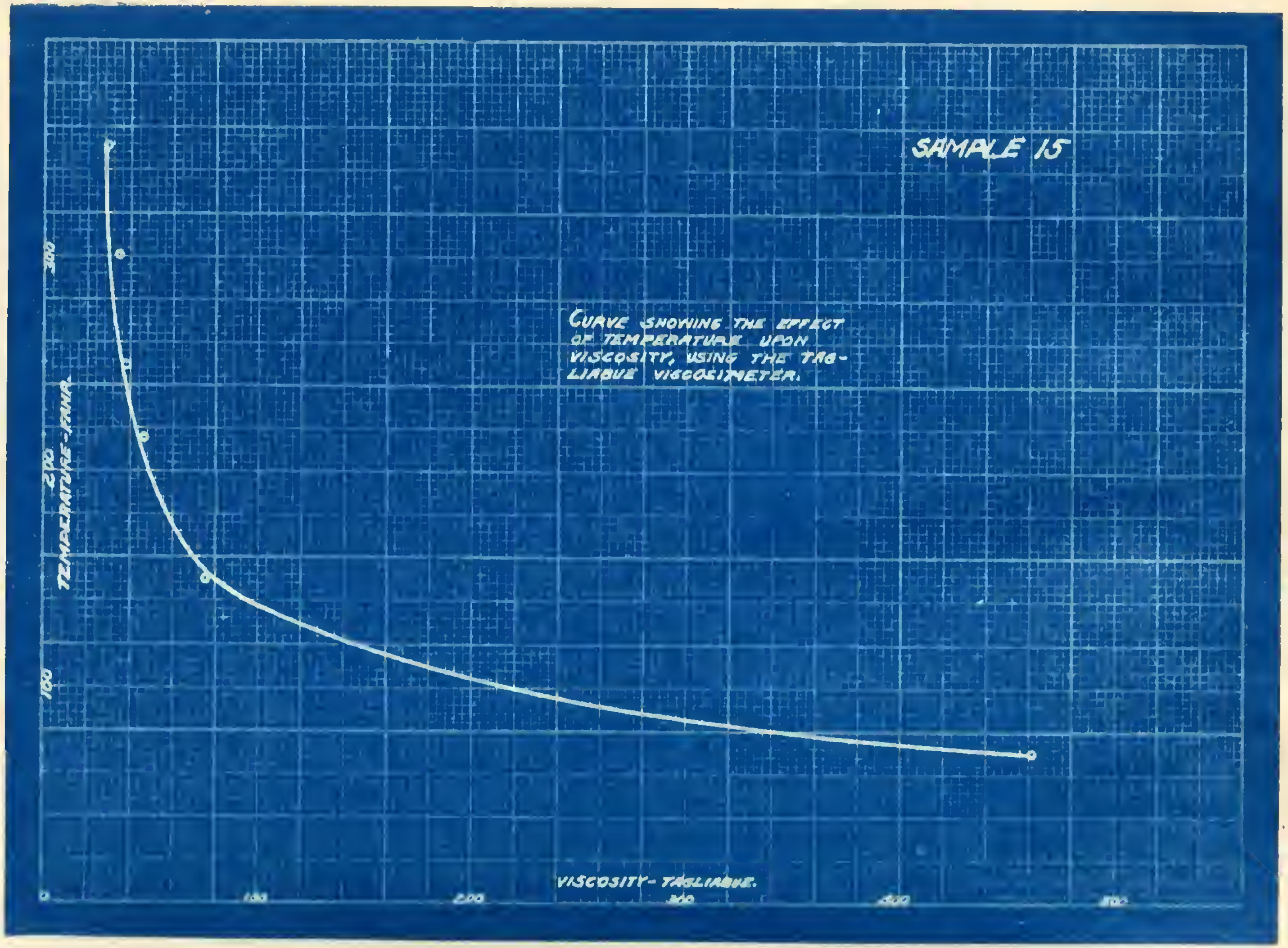
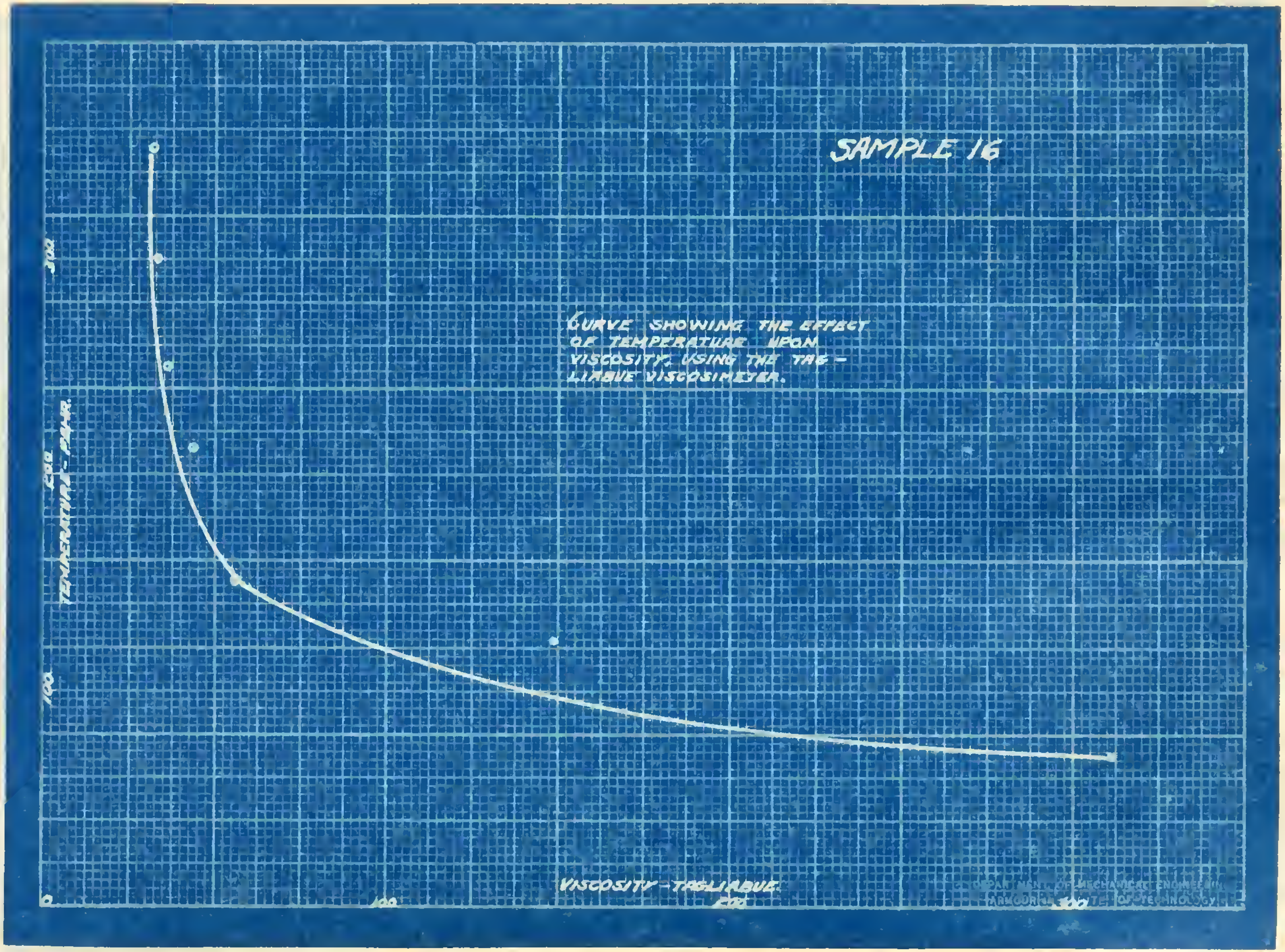
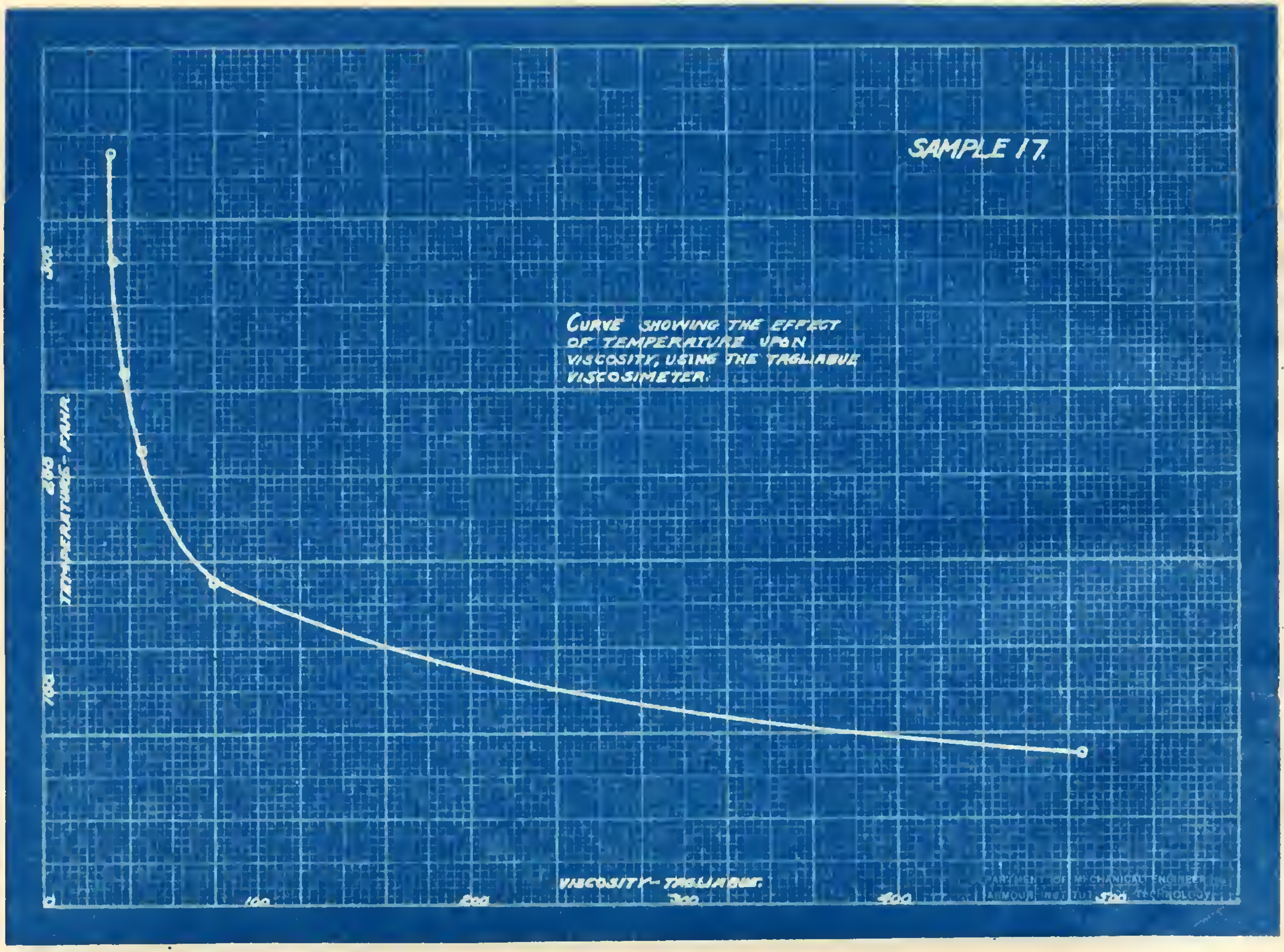

SAMPLE 15
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.
TEMPERATURE-FAHR.
100
200
300
VISCOSITY-TAGLIABUE.
0
100
200
300
400
500



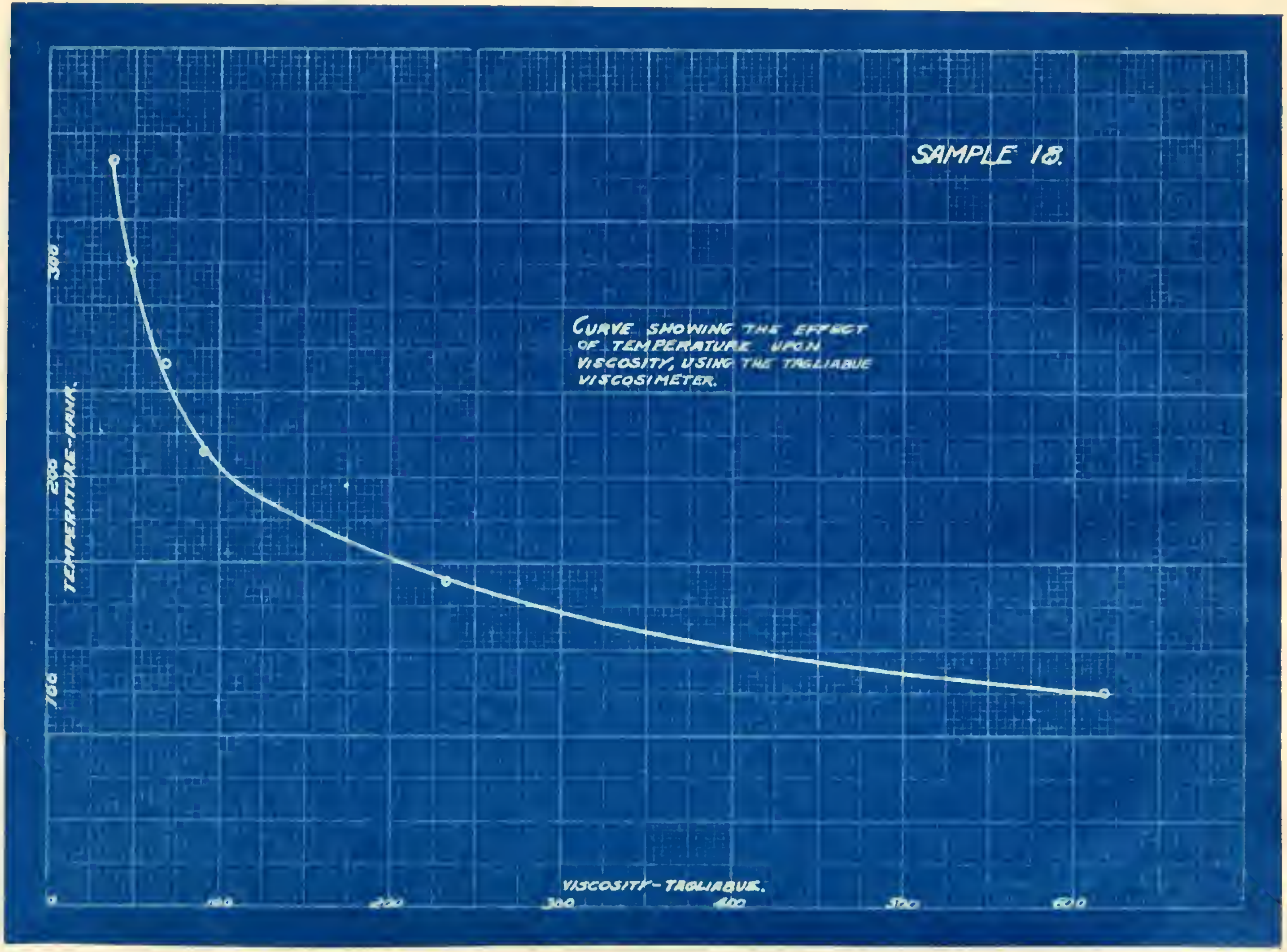
SAMPLE 16

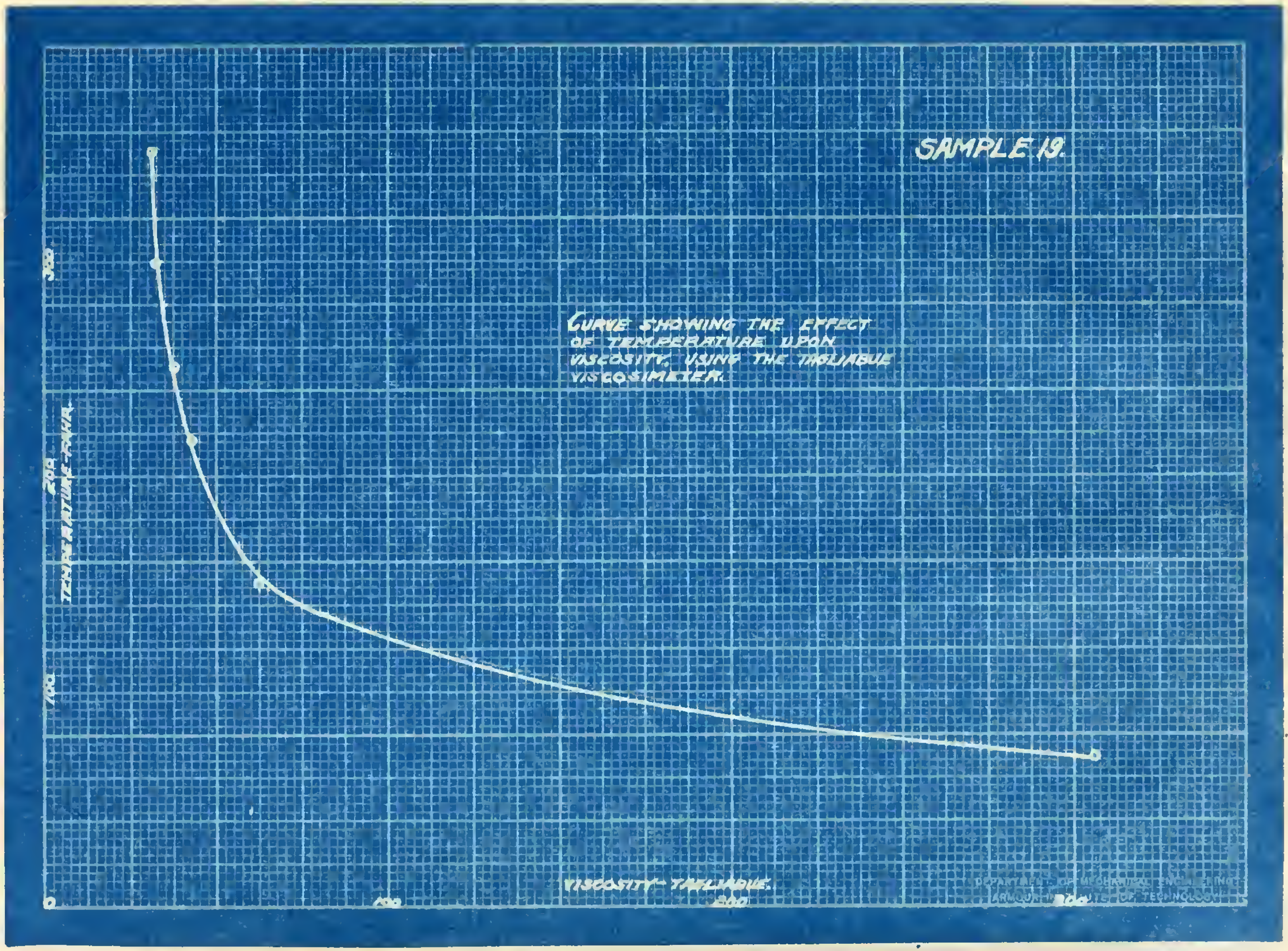
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.

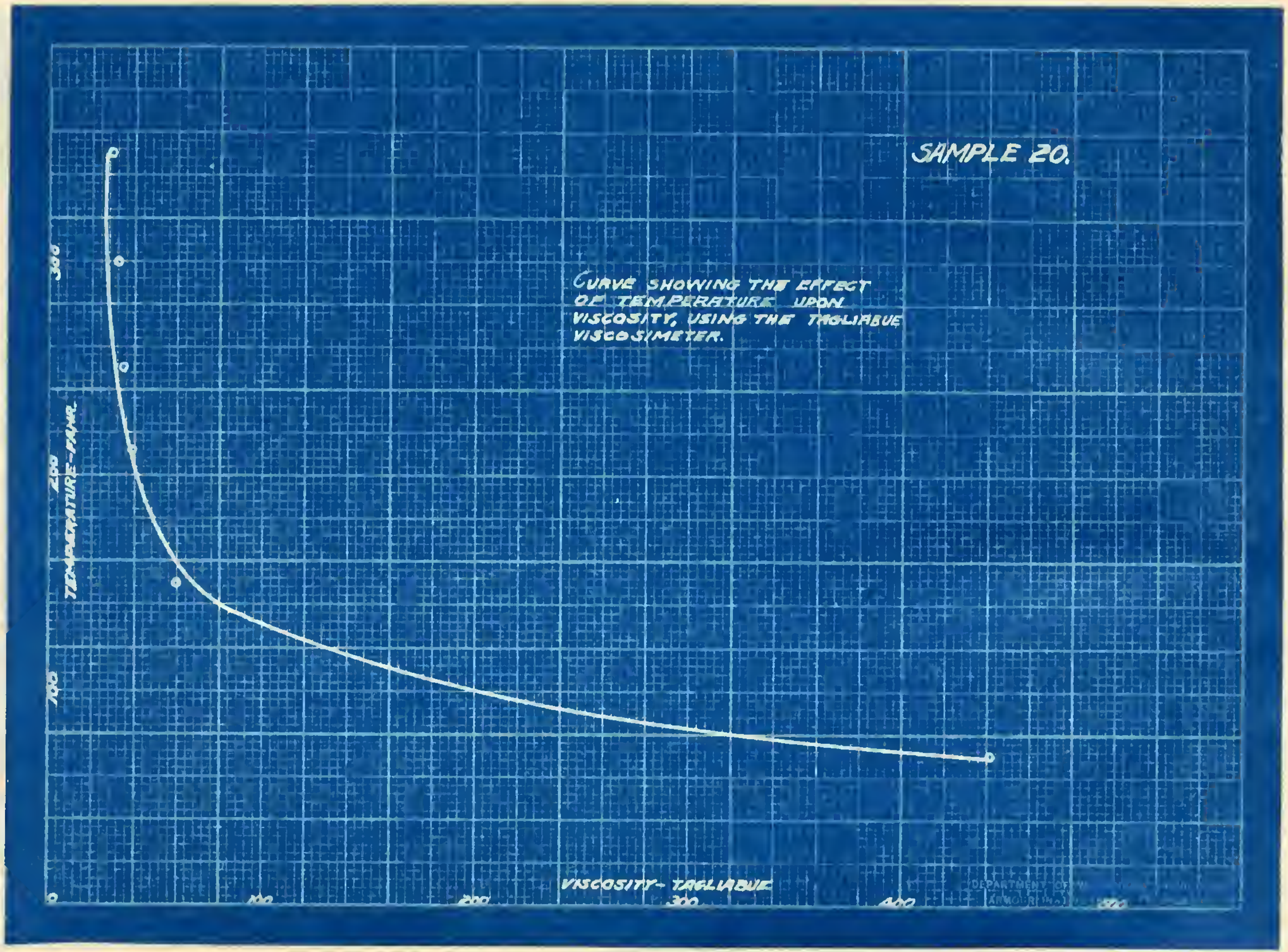


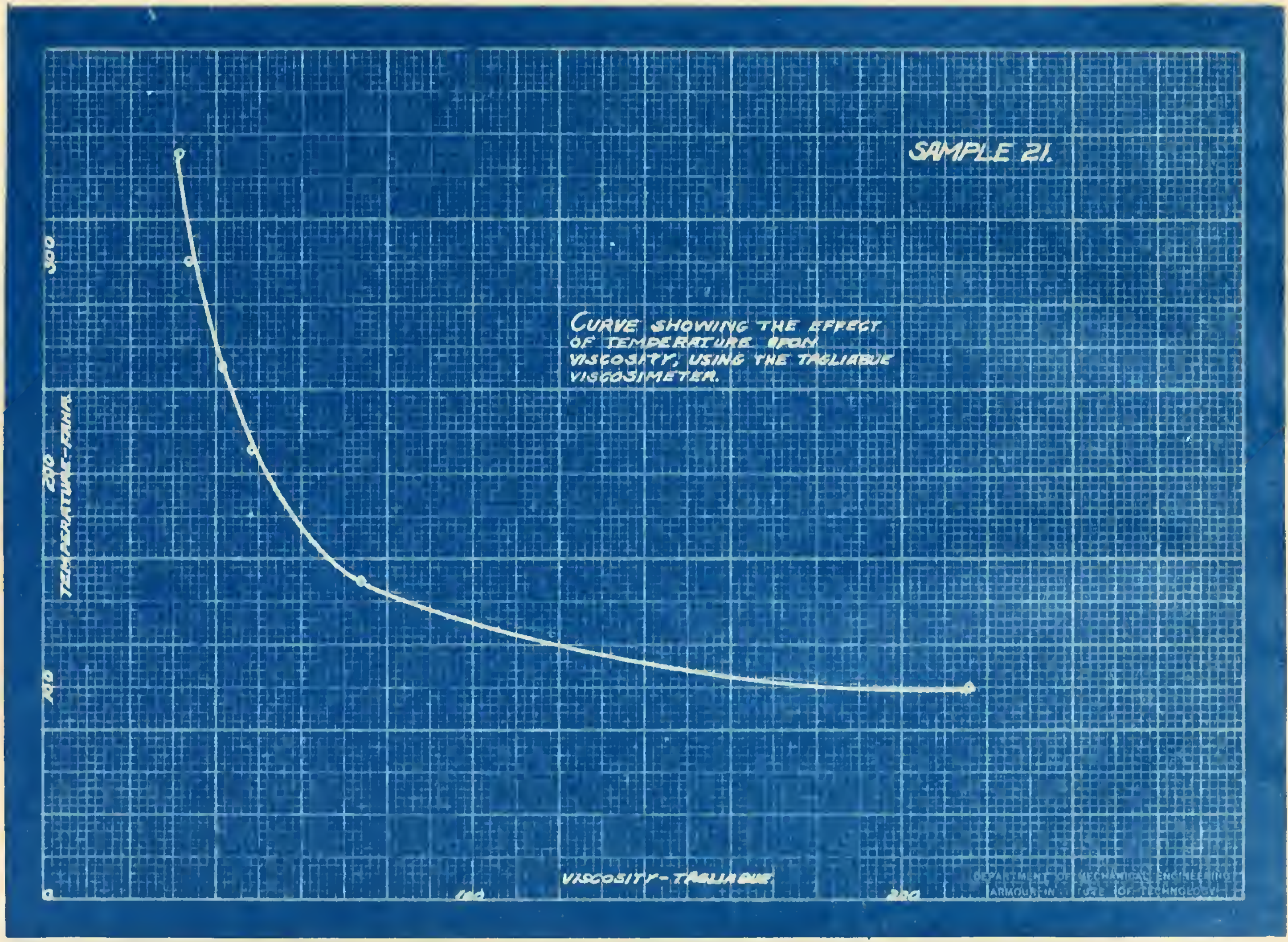
SAMPLE 17.

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.


SAMPLE 18.
CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.
TEMPERATURE-FAHR.
300
200
100
VISCOSITY-TAGLIABUE.
0
100
200
300
400
500
600

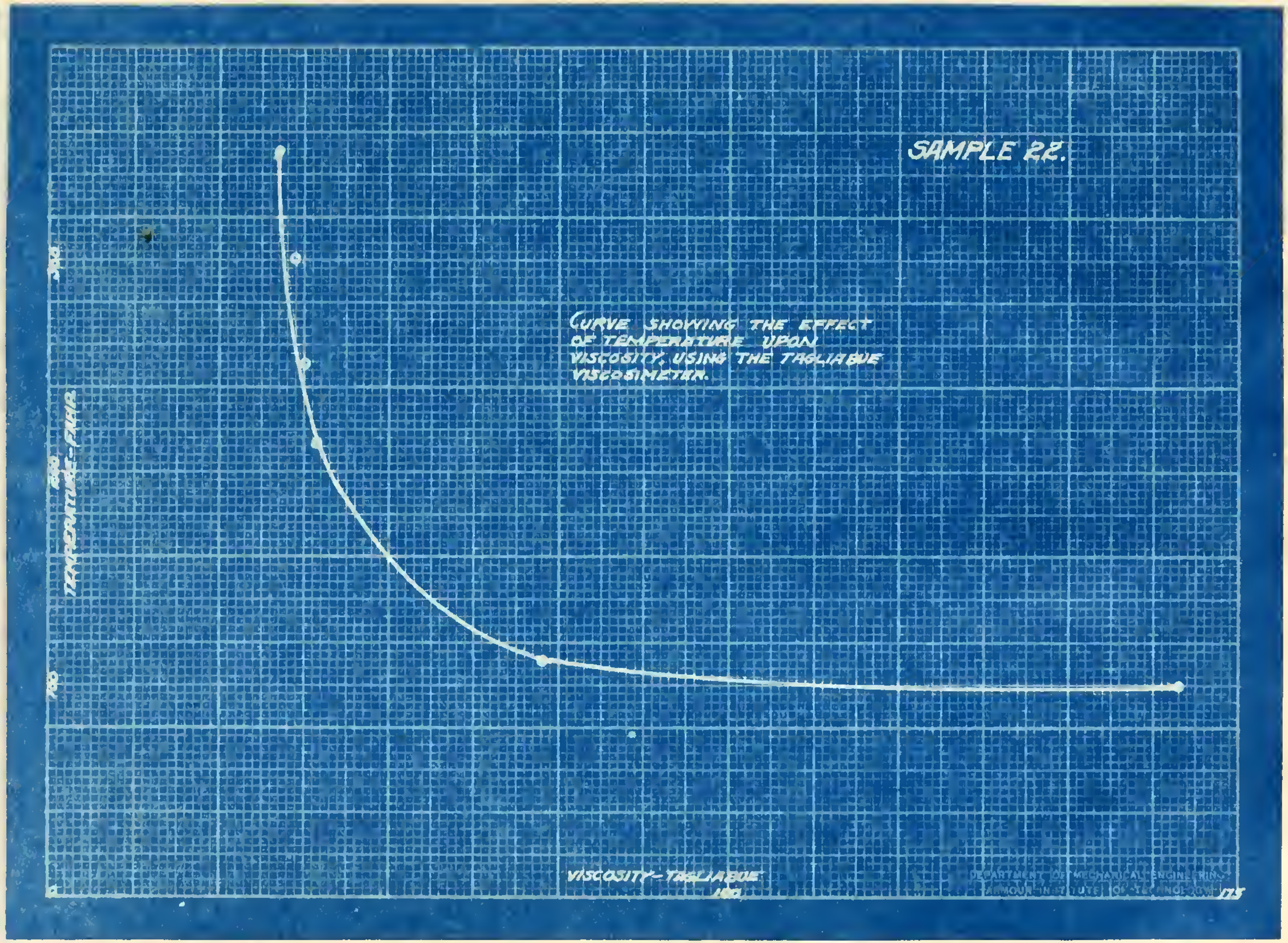

SAMPLE 19.
CURVE SHOWING THE EFFECT
OF TEMPERATURE UPON
VISCOSITY, USING THE TAGLIABUE
VISCOSIMETER.
TEMPERATURE-FAHR.
300
200
100
0
VISCOSITY-TAGLIABUE.
100
200
300
DEPARTMENT OF MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY


SAMPLE 20.
CURVE SHOWING THE EFFECT
OF TEMPERATURE UPON
VISCOSITY, USING THE TAGLIABUE
VISCOSIMETER.
TEMPERATURE-FAHR.
300
200
100
0
100
200
300
400
500
VISCOSITY- TAGLIABUE
DEPARTMENT OF
ARMOUR INST



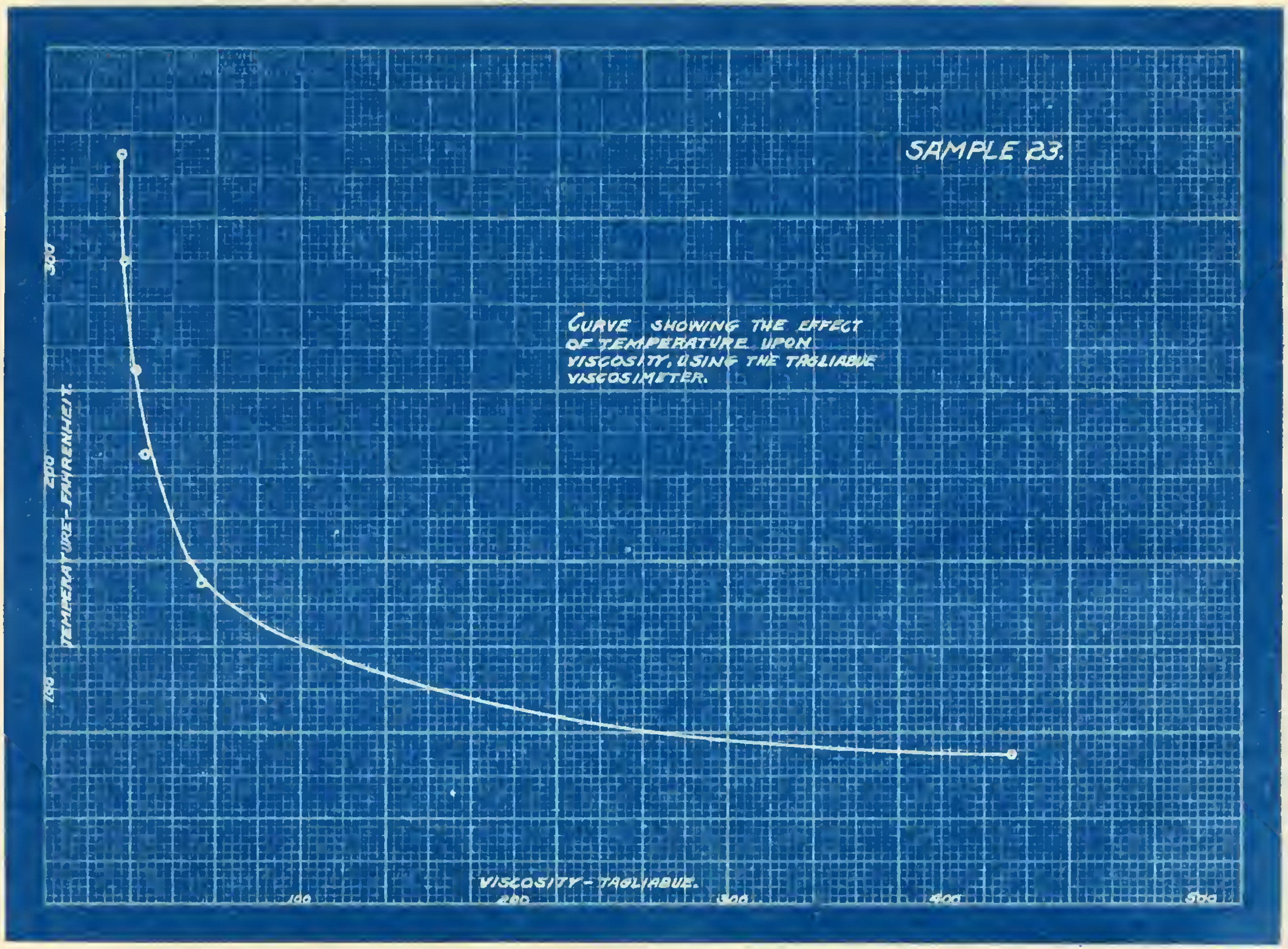
SAMPLE 21.

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY; USING THE TAGLIABUE VISCOSIMETER.



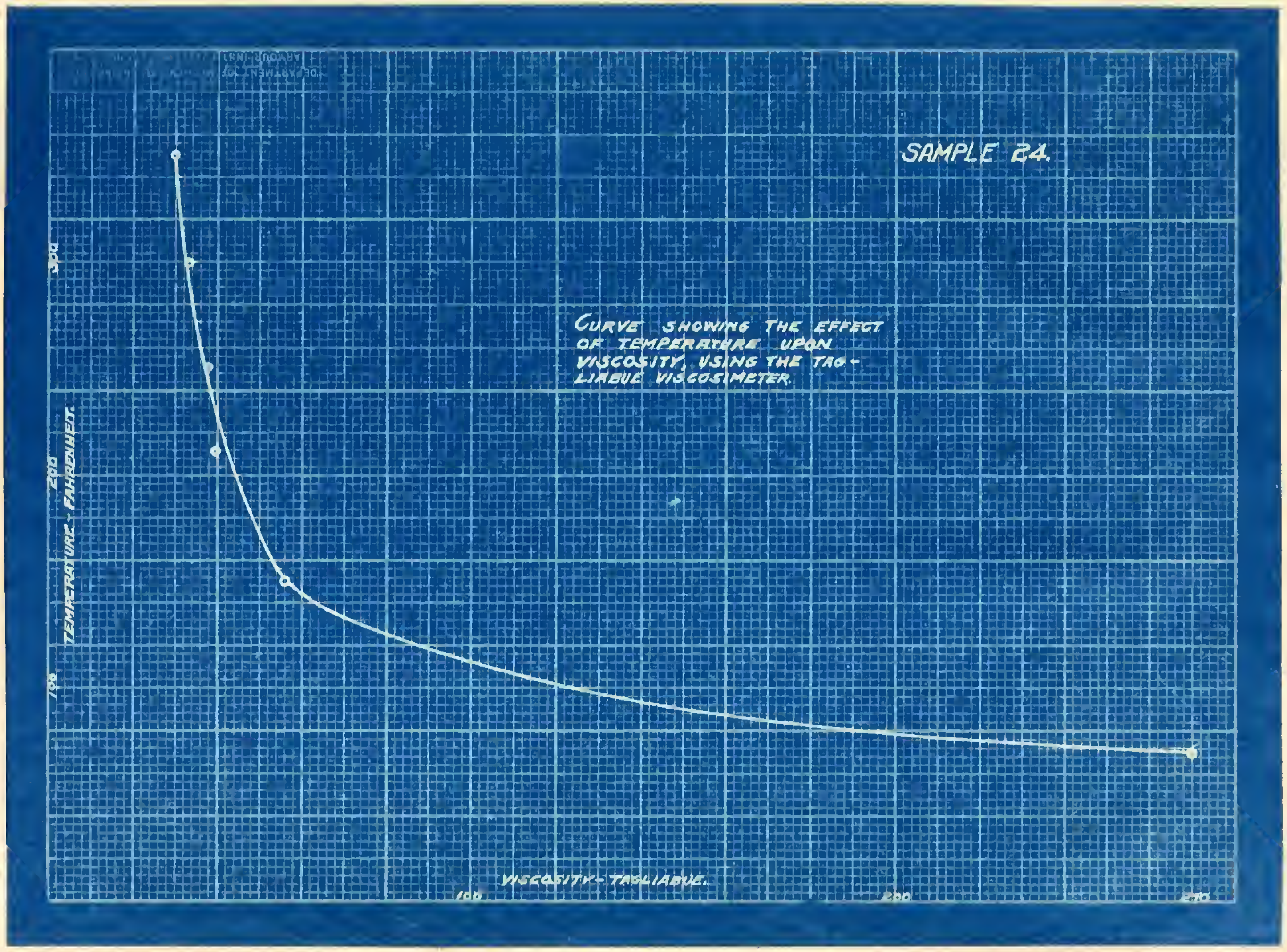
SAMPLE 22.

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.



SAMPLE 23.

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.



SAMPLE 24.

CURVE SHOWING THE EFFECT OF TEMPERATURE UPON VISCOSITY, USING THE TAGLIABUE VISCOSIMETER.

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